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SHOCK AND VIBRATION BULLETIN

NO. 9. Symposium (10th)

NAVAL RESEARCH LABORATORY
14 April 1948. [U].



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FOREWORD

The furtherance of a comprehensive shock and vibration program for the future needs of National Defense depends upon the utilization of new ideas and novel techniques. Moreover, to keep our designers and technologists in the forefront of applied science, it is essential to disseminate pertinent information as soon as it becomes available.

The contents of this Bulletin demonstrate splendid cooperation in prompt exchange of recently accumulated knowledge in this field. The material assembled presents, also, a study in contrast. Certain similarities and differences between field tests of ships and other types of military vehicles are discussed. In approach and point of view, the British ship target trials are both revealing and instructive to us. The procedures described and the results obtained are impressive. Planning, organization, and experience are represented in the trials routine. The fact that over 90 percent of the recordings were suitable for analysis, indicates a professional "know-how" which is as yet beyond our ken.

Our full-scale quantitative tests are just getting under way. Plans and procedures are still in the formative stages. We are maturing through precept and example--sometimes the hard way, by trial and error--but we are acquiring knowledge, and our objectives are in focus.

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**THE TENTH SYMPOSIUM/
Naval Research Laboratory
14 April 1948**

**ADMIRALTY FIELD INSTRUMENTATION
FOR SHOCK AND VIBRATION INVESTIGATION**

By

J. Pausey, R. N. S. S.

There is presented an outline and discussion of the instruments used by the Royal Navy in conducting ship target trials. Relative merits of the measuring devices employed and the manner of processing the resulting data are described.

It became apparent quite early in the recent war that the effects of noncontact underwater explosions on ships were much more serious than had been anticipated and that it was quite possible for a ship to be put out of action as a fighting unit, although the hull was not seriously damaged, due to the disruptive effects of shock on the internal equipment. At first there was little coordination in efforts to investigate these phenomena, individual design departments carrying out their own experimental work and trying to devise means to combat the trouble. At that time the Electrical Department of the shore establishment H.M.S. VERNON, the function of which was to represent sea-going opinion in connection with the design of electrical equipment, became interested in "shock" effects.

It was apparent to this Department that little was known of the magnitude and severity of shock and vibration effects experienced and that trials would have to be carried out under sea conditions to get some idea of these magnitudes, so that suitable methods of recording them on a large scale could be developed. This first trial was carried out in January, 1940

in the minesweeper H.M.S. BORDE during a routine sweeping trip. The instruments used were crude and simple "shock" meters, each of which consisted of 12 spring steel strips of lengths graded from 3 cm to 10 cm. One end of each contact was firmly fixed to a steel block; the other had riveted to it a small mass and was free to move 1 cm downward toward a steel base. Any contact which moved 1 cm was arranged to clip down. Six of these meters were fitted to give plus and minus accelerations in longitudinal, athwartships, and vertical directions. Crude and unsuitable as these instruments were, they did give some idea of the magnitude of acceleration and displacement which might be expected.

Methods of obtaining continuous records were considered next. The functions which it was possible to obtain by various methods were acceleration, velocity, and displacement. It seemed that velocity might be the best function to measure, as it would be possible by one operation to obtain either of the other values. A velocity meter was constructed, consisting of a search coil operating in the annular

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gap of a cylindrical electromagnet which was suspended on a spring system of low natural frequency. The magnetic field in the gap was found to be uniform except at the extremities. The base of the instrument, which carried the search coil, was bolted rigidly to the item under test. On being subjected to shock motion, the search coil moved relative to the spring mounted mass and, therefore, had a voltage generated in it proportional to the rate of change of flux linkage which (as the field strength in the gap was uniform) was proportional to the velocity of the search coil relative to the magnet. This could reasonably be taken as the absolute motion of the base over the early part of the record before movement of the magnet introduced an error. Such meters were coupled to R-C amplifiers and thence to C.R.O.'s fitted with continuous recording film cameras, so that it was possible to obtain a velocity/time curve. Using this type of instrument, small-scale sea trials were carried out in H.M. Ships EURYALUS, LONDON, VANOC and JAVELIN.

By this time it had become apparent that the investigation of shock and vibration effects were of extremely widespread interest and in order to study the problem fully and to avoid duplication of effort, the Admiralty Shock Committee, which consisted of representatives of Admiralty design and research departments, was formed. Part of the terms of reference of this committee were to control and direct experiments necessary to investigate the nature and severity of shock in warships resulting from noncontact underwater explosions. This naturally introduced the question of instrumentation on a large scale.

In the CAMERON Trials various types of accelerometers, displacement meters, velocity meters, strain gauges, and resonance meters were used. The troubles experienced in operating these various instruments and the results obtained have been set out fully in the CAMERON Report and it is not proposed to enlarge further on

that trial in this paper. Results obtained tended to confirm the opinion that velocity was the simplest function to measure and that displacement and acceleration could be obtained from the velocity records. From then on, other existing methods of continuous recording were dropped, and velocity meters came to be used almost exclusively. It was realized that the instrument as it stood was by no means ideal. It weighed 35 lbs, could cope only with maximum displacements up to 2 inches total, and introduced errors in the record (due to movement of the seismic mass) quite soon after the start of recording. On the other hand, as far as 'shock' was concerned, the important part of the record was obtained. Furthermore, the impedance of the instrument was low, and it gave a comparatively large voltage output. This made possible the use of low gain amplifiers having maximum amplification of about 200, which was of great value in work on board ship where pickup effects were liable to be very troublesome. Attempts were made to develop the instrument in the way of weight reduction and increase in measurable displacement, but, owing to staff shortage and the necessity for keeping the sea trials programme going, these progressed very slowly.

It was evident that the method of installation of recording equipment used on the CAMERON (namely, putting everything in the target vessel) would not be practical in the future trials envisaged, and it was decided to obtain a small vessel and to fit it out as a floating laboratory. The ship selected for this work was M.V. ENDSLEIGH - a small coasting vessel (pictured in Figure 1) of some 200 tons, length 103 feet, and beam 23 feet. The original hold space was subdivided and decked in to form compartments as shown in Figure 2. The instrument room contained all the C.R.O.'s and other recording equipment (see Figures 3, 4, and 5) which were mounted on a sprung bench.

A continuous processing machine for 35 mm film (shown in Figure 6) was in-

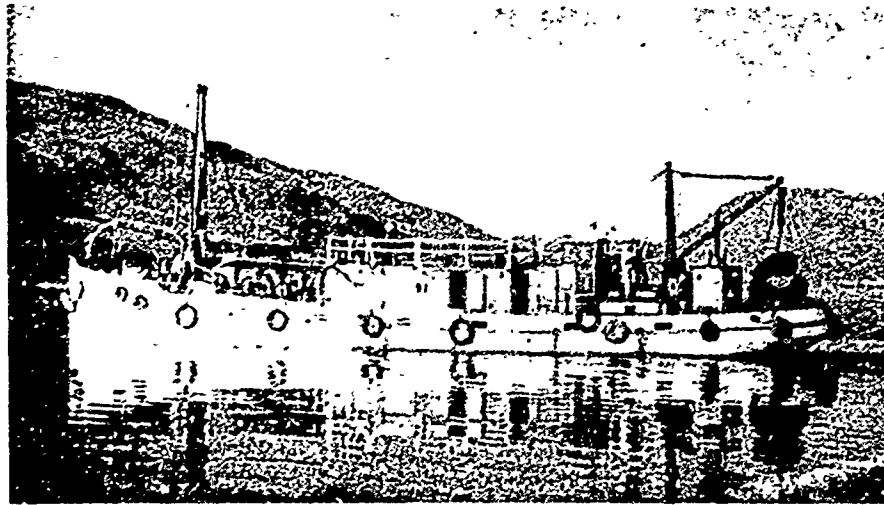


Fig. 1 HMS ENDSLEIGH

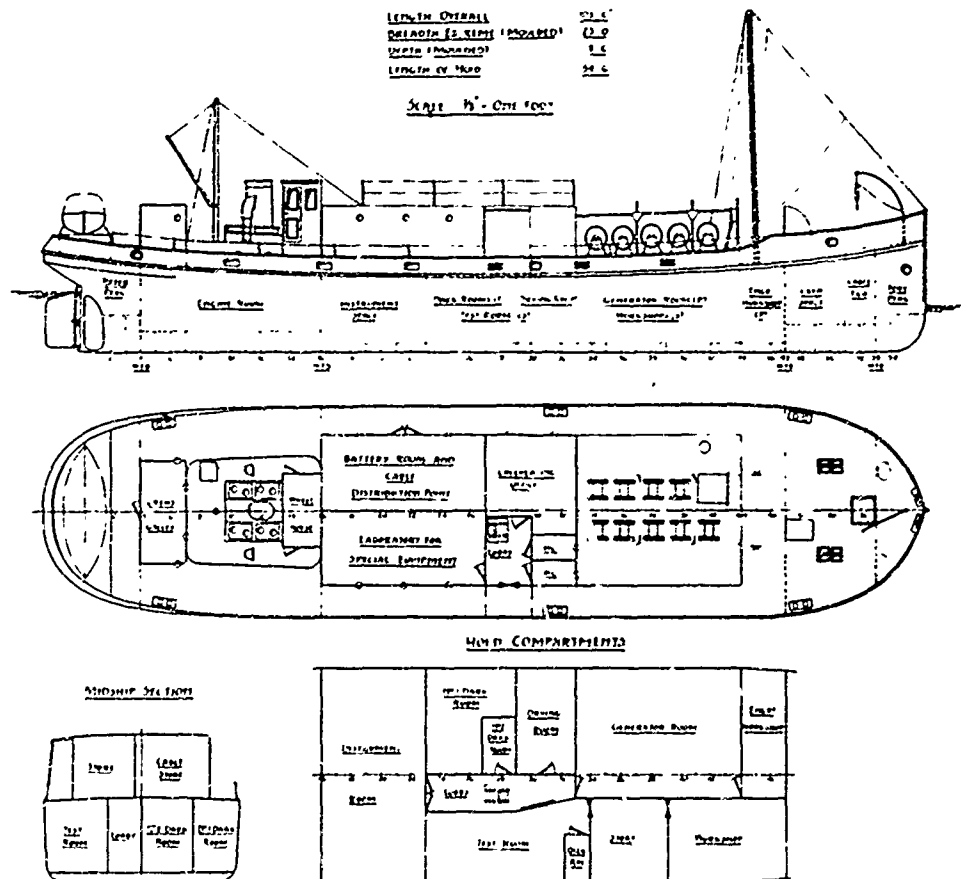


Fig. 2 Arrangement of Compartments

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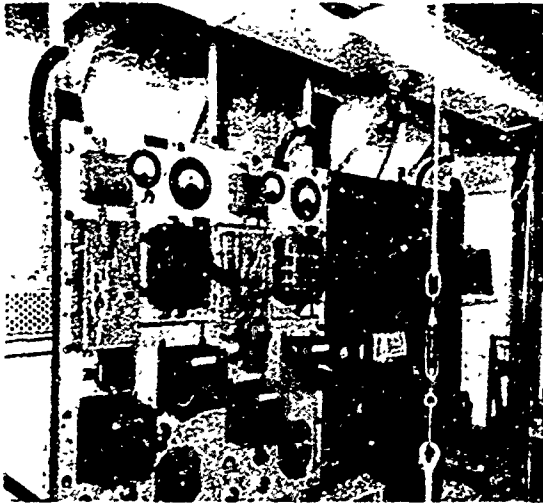


Fig. 3 Instrument Space: Supply and Instrument Panel (Looking to Starboard)

Fig. 4 Instrument Space: Instrument Bench (Forward Side)

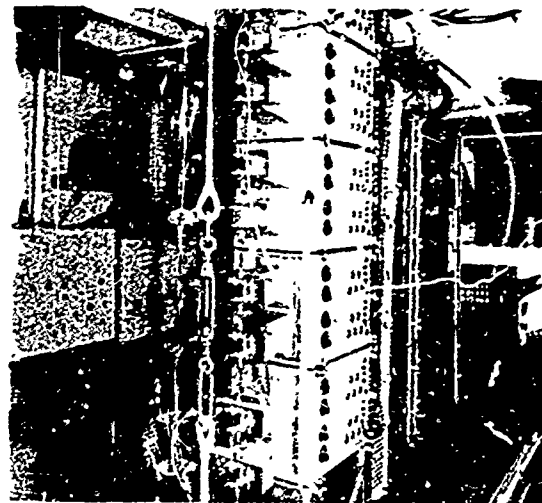
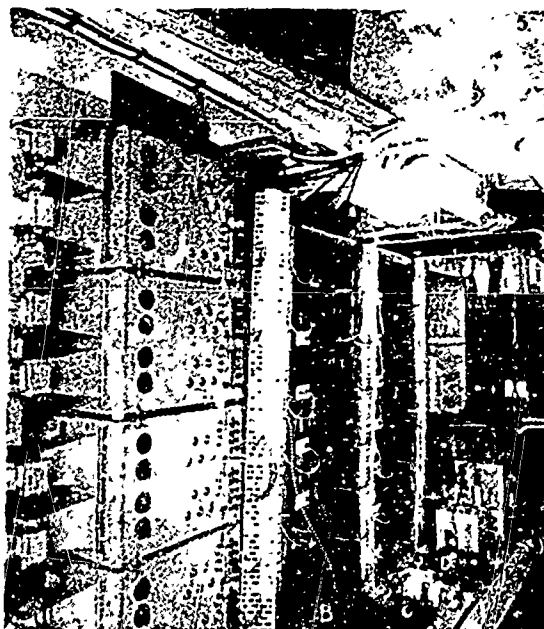


Fig. 5 Instrument Space: Instrument Bench (After Side)



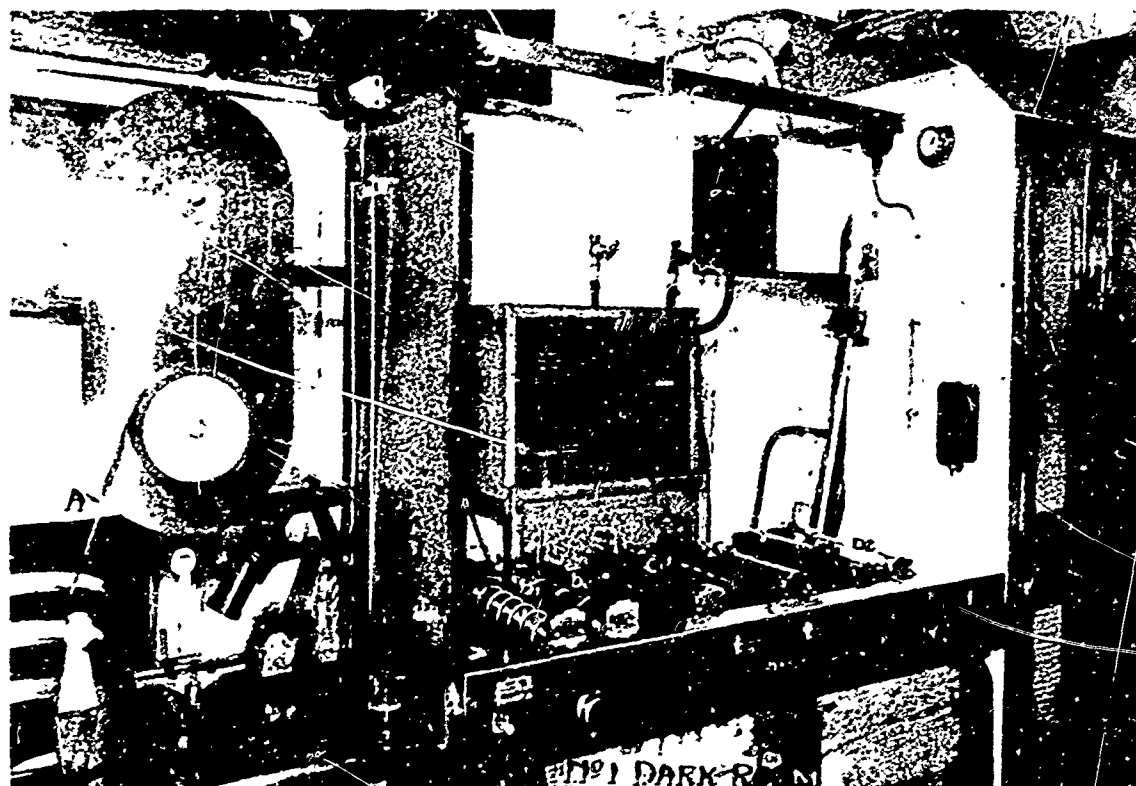


Fig. 6 No. 1 Dark Room. Processing Machine for 35 mm Film (Looking Aft)

stalled in No. 1 darkroom. In addition, the ship had a small machine shop (Figure 7) and a compartment known as the test room (Figure 8) where testing, repair, and construction of electronic equipment were carried out.

For power supply, two diesel generators were installed, a main set of 50 kw, 220 volts D.C. in the generator room and an auxiliary 30 kw, 220 volts D.C. set in the main engine room. The main A.C. supply for instruments was provided by a 14 KVA motor alternator supplied from either diesel generator. In addition, a 5 KVA motor alternator, supplied from a 110 volt, 150 ampere hour battery in the battery room was fitted to provide steady voltage supply to the amplifier during recording.

As previously stated, the amplifiers, oscillographs, recording cameras, and auxiliary apparatus were mounted on a spring supported bench, 12 x 5 feet, situated centrally in the instrument room.

Provision was made for recording 38 signals simultaneously. Each amplifier is associated with a particular oscillograph trace and the inputs of all amplifiers are permanently wired by means of single core screened cable to plug points on the instrument room control board. These may be linked up as desired by means of flexible leads to similar plug points which are wired permanently to the instrument distribution board in the battery room. This board was the point at which connection with the target ship was arranged.

The arrangement envisaged was that the target vessel would be moored head and stern and that a dumb barge would also be moored in a similar manner at a safe distance and in line with the target. Instruments were mounted in the target vessel, leads being taken to a common terminal board sited within the target at some convenient point. From this board, connection was made to the laboratory vessel by means of suitable multi-core, watertight cables. The multi-core

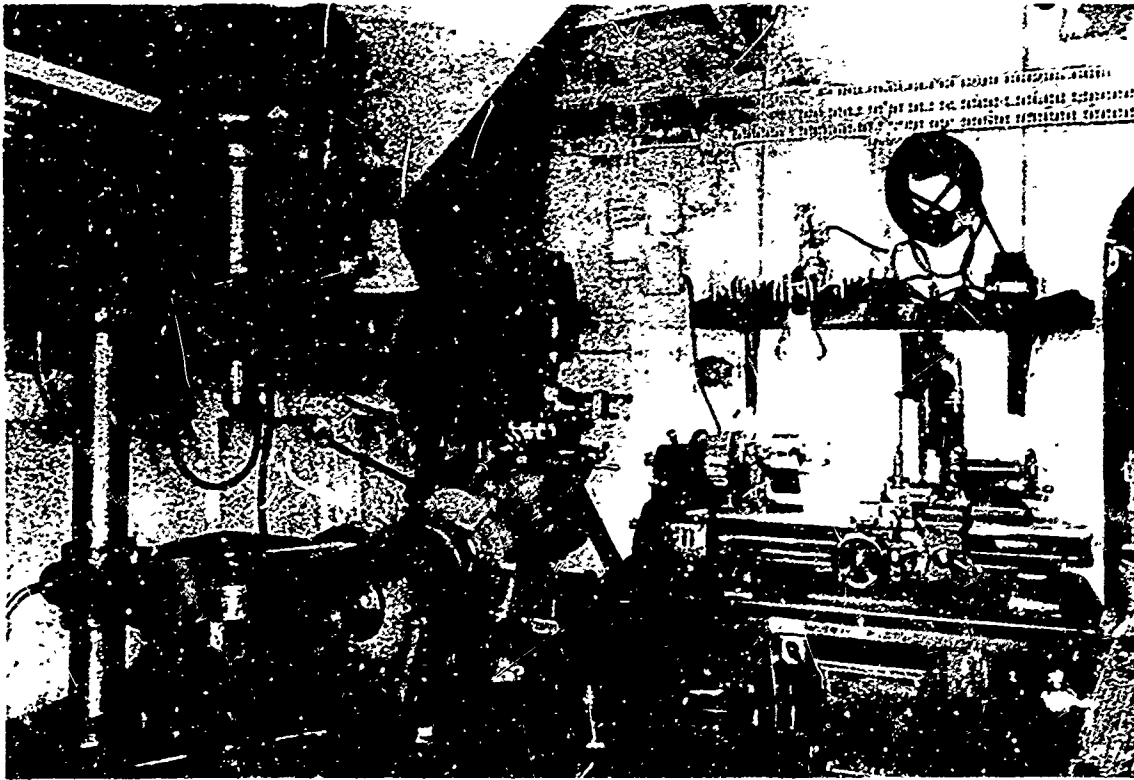
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Fig. 7 Workshop (Looking Aft)

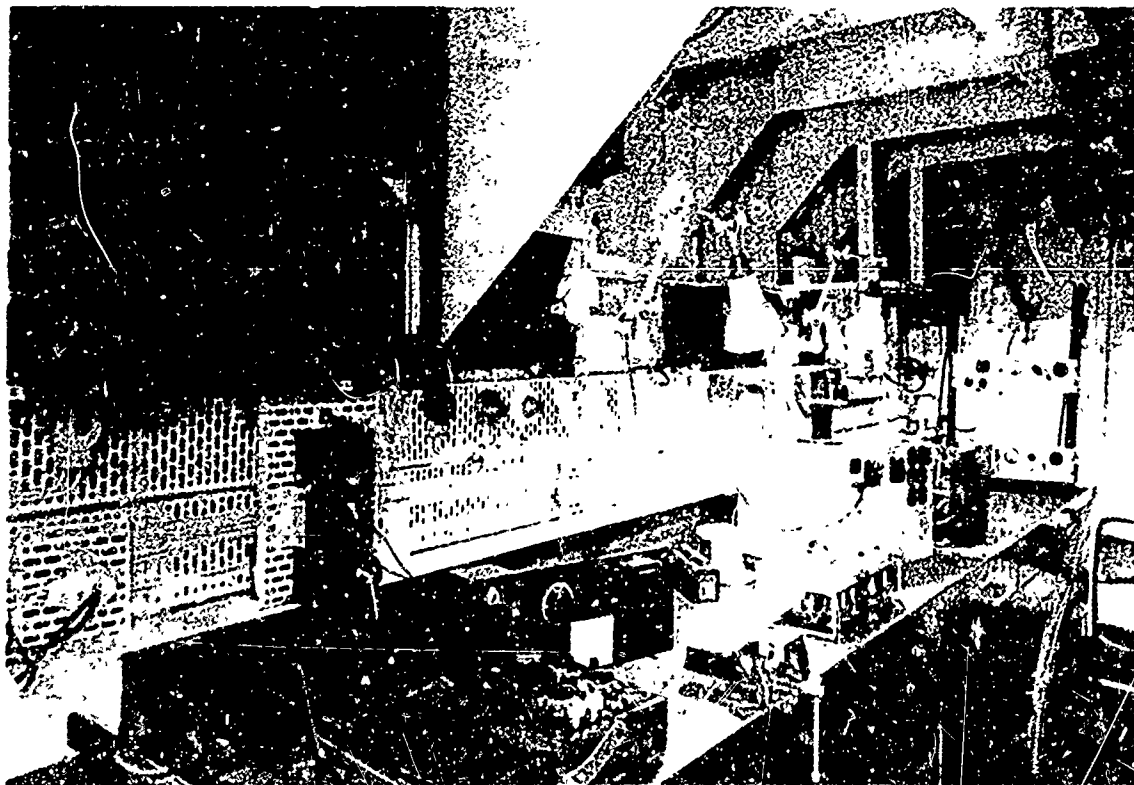


Fig. 8 Test Room (Looking Aft)

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cables were carried across the water on a series of floats. The latter were secured together by means of steel wire ropes which were arranged to prevent any strain, due to rough weather, coming upon the cables. This arrangement proved very satisfactory, although great care had to be taken to avoid any rough edges at which chafing of the cables might occur.

It was possible to slip the cables from the ENDSLEIGH, if an emergency arose, and to be away from the trials site within 15 minutes.

The staff required to operate this vessel consisted of six scientific officers, two laboratory mechanics, and two labourers, together with the ship's crew consisting of a skipper, two engineers, a mate, and two deckhands.

The trials routine adopted was as follows: Two hours before the time of firing a shot, all the bench equipment was checked over to ensure that C. R. O.'s, cameras, amplifiers, and auxiliary gear were functioning correctly. Then each individual instrument circuit was tested for continuity and insulation resistance to be sure that no cable or other fault had developed. Next, each instrument was checked to ensure that it was operating. Finally, all velocity meter magnet currents were accurately adjusted.

At the same time, the naval firing party had been fitting the charge and preparing the lead for remote electrical detonation, while the working party were checking pumping arrangements, closing watertight doors, etc.

Three quarters of an hour before the shot, the instrument party closed up in the instrument room on ENDSLEIGH and loaded film in the cameras, switched on amplifiers, C.R.O.'s, etc. The charge was lowered into the water and its firing cable connected through to ENDSLEIGH where it was tested for continuity and insulation resistance and finally coupled to the firing battery circuit. At the appropriate moment, an automatic firing switch was energized in the instrument room. This started the cameras, injected a calibrating signal into the amplifiers, and fired the charge.

This arrangement has been used with but minor modifications in all the trials carried out since CAMERON.

Trials have been completed on a PARTHIAN Class submarine PROTEUS, a specially built centre section of an A Class submarine JOB 9 the destroyer AMBUSCADE, and the cruiser EMERALD. The most novel of these trials were those carried out on JOB 9, as this target was submerged for most shots. In order that connections could be made to the target, a float was introduced at the end of the buoyant cable line and a large bight of cable (about 200 feet long) was left between this float and JOB 9. The cables were led into the pressure hull through special submarine cable glands. Throughout these trials velocity meters of the original type have been the main means of instrumentation.

The reliability of recordings has improved progressively, and it is estimated that more than 90 percent of the 4000 records taken have been suitable for analysis.

In addition, certain maximum recording instruments, such as relative displacement indicators and copper crusher accelerometer units, both of which have been fully described in the CAMERON Report, were used.

Certain other methods of recording have been devised and tested in trials subsequent to CAMERON. On PROTEUS an attempt was made to measure whipping of the ship by means of an instrument which was called the low-frequency shock meter. The requirement from this instrument was that it should measure low frequency motion of the order of 2 cycles per second but having large displacements. The instrument consisted essentially of a transformer of variable coupling (Figure 9). The secondary coil embraces a core which is common to two magnetic circuits and movable in an air gap with respect to them. This arrangement was employed for the reasons that it allows a convenient sensitivity adjustment and that it reduces the unbalanced varying magnetic forces to a second order of magni-

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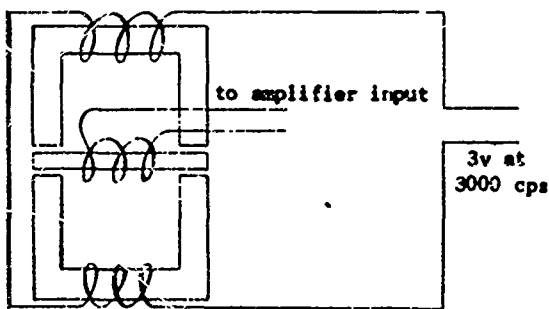


Figure 9

tude (Figure 10). The natural frequency of the instrument was approximately 60 cycles per second and it was subjected to slight oil damping.

The transformer primaries were fed with a 3000-cycle per second 3-volt supply. The instrument had a linear response for accelerations up to 2 g. The output of the instrument was set so that the band width was reduced to zero by the application of an acceleration of 2 g. This acceleration was easily obtained simply by inverting the whole instrument. A record is shown in Figure 11, the variation in width of the 3000-cycle band being proportional to

ARMATURE ADJUSTED SLIGHTLY OFF BALD POSITION IN AIR GAP
FIELD COILS (C) ARE SUPPLIED WITH 3000 CYCLES AC AT 3000 CPS

FIGURE 10

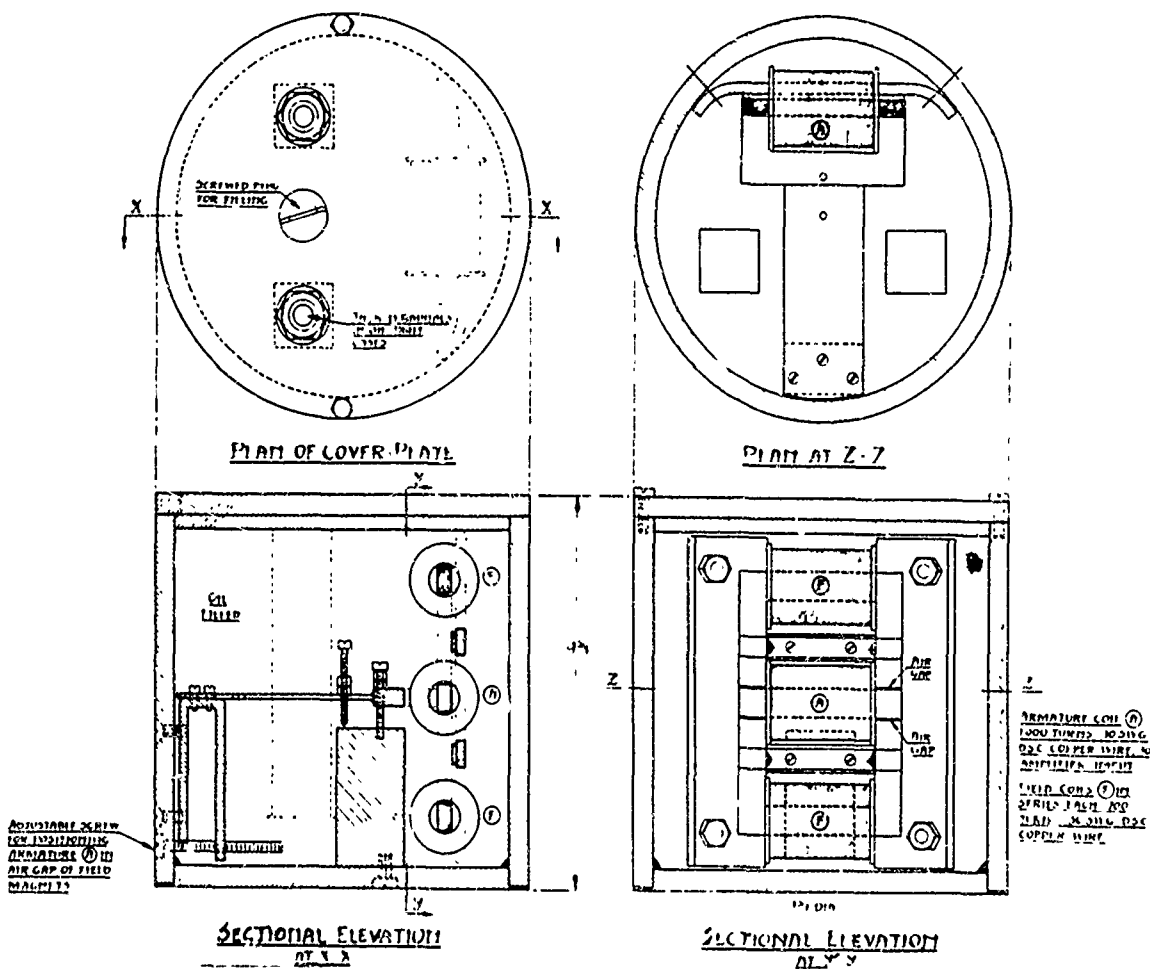
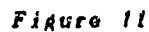


Figure 10

9



Attention was then turned to examining the possibilities of producing electronic means of adding the requisite proportions of the output signal.

The first amplifying mixers developed made provision for the addition of both single and double integral proportions, but it was found that damping was low enough to allow the first integral term to be neglected. Within the limits of this assumption the ratio of output to input voltage of the correcting network as a function of frequency is proportional to $\frac{\omega_0}{\omega}$. This quantity is plotted in Figure 12.

Various methods of integration were attempted but without complete success.

The output obtained from the meter was very much smaller than that from the standard velocity meter, owing to the stiffness of the springs which resulted in very limited relative movement between magnet and search coil. In consequence high amplification became necessary. This brought in its train all the usual troubles of a ray pickup, valve noise, and vibration effects which are very much more difficult

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to eliminate on board ship than under shore laboratory conditions. In addition, it was necessary that the device should have both a frequency response approximating that which has already been discussed and good transient response. In the methods which were tried, one or the other could be obtained but not both. Consequently, it was felt that further investigation on the laboratory ship would not prove fruitful, and the question of electronic correction has been dropped temporarily until such time as it can be investigated in some shore laboratory.

Theoretically, it should be possible to analyse and correct records obtained from the H.F.V.M., but this involves obtaining the constants for each individual meter and carrying out a tedious and lengthy graphical reconstruction. In practice, where one requires to know the results of one shot before carrying on with the next and where a large number of meters would be in use, it is not feasible.

It is possible that, having obtained the uncorrected record and knowing the constants of a meter, it might be feasible to obtain the true answer quickly by some mechanical means. This is being investigated.

Yet another problem which arose was the question of measuring the motion of the shell plating. It was not possible to

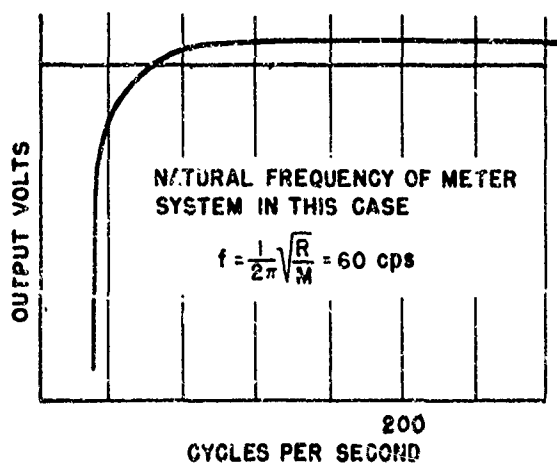


Figure 12

mount a standard velocity meter in the ordinary way, as the weight of the instrument would have materially affected the motion of plate. The method used was simply to remove the search coil from a meter and mount it on the plate. The magnet was reversed in the meter body and the body attached to a robust channel iron framework which was rigidly attached between the two frames which bounded the plate under investigation. Adjustment was provided so that the search coil could be centered in the magnet gap. Thus the load on the plate was reduced to a matter of a few ounces instead of the full 35 pounds of the whole meter. This device worked quite satisfactorily, although great care had to be taken in centering the search coil in the magnet. There was considerable wastage in search coil formers, as damage was caused when they were tilted (due to the directions of motion of the plate) instead of moving axially in the magnet gap.

The question now arises of the future developments expected in instrument technique. It is considered that the magnetic principle of the velocity meter is still the most reliable method of recording in quantity.

The instrument as it stands has the following disadvantages: It is too heavy, records faithfully for too small a displacement for a number of cases, is subject to spring error, and requires a supply to energize the magnet. In the near future and without interfering with trials progress, it is hoped to redesign the meter to remedy some rather obvious crudities in the design.

The framework of the meter will be made in some of the light alloys which are now available. This should bring considerable weight saving and thereby permit designing for a larger displacement without any weight increase. The electromagnet, it is hoped, can be replaced by a permanent magnet in one of the modern magnetic materials ('Ticonal' or 'Alnico') which will retain their magnetism even when subjected to repeated shocks. This would simplify

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considerably the operation of numbers of meters. If at all possible, the natural frequency of the magnet on its suspension will be reduced, but it is not considered that much improvement can be expected in this direction.

Finally, I will say a few words about a new method of recording which is, as yet, in its embryo stages and is completely untried. As far as is known, the principle has not been used before.

The main components of the circuit will be a square wave generating circuit followed by a simple integrating device. The recording head will consist of a lightly suspended mass which is constrained to move between two spring contacts. The purpose of the contacts is two-fold: To provide a bias which will trigger the square wave generator and to give a pulse of energy to the moving mass to send it towards the opposite contact, where a similar cycle will take place. In the undisturbed state,

adjustment will be made so that the time intervals are equal in each direction. Thus a uniform square wave will be produced.

This, on being integrated, will give a triangular wave. If the base of the instrument is attached to an object which is given a shock motion, the time taken for the mass to move between contacts will be modified by the motion of the base, and successive half cycles of the square wave will not be equal. Thus, instead of the integrated wave returning to zero at each cycle, it will be displaced and a trace, consisting of a series of triangular steps, will be produced.

The important factor appears to be that the time interval for undisturbed motion should be reasonably large compared with the time changes expected from the motion. The advantage appears to be accuracy of recording, irrespective of the displacement imposed. Little more can be said about this item at present.

DISCUSSION

D. E. MARLOWE, NOL: I would like to ask what the periodical impulse or carrier frequency oscillation for the new recording head for the square wave instrument is supposed to be.

J. PAUSEY, R.N.S.S: That will depend upon what is to be measured. If you want to measure whipping, you will be able to use very low frequency. If the measurement is going to be shock motion, it may not be possible to use the instrument, as a much higher carrier frequency will be necessary. At present, this work is in the embryo stage.

J. P. WALSH, NRL: What has been your experience with wire strain gages on shipboard trials?

J. PAUSEY: From my own experience, it was very difficult to use these gages on target ships. We have found that we could get them to work in the laboratory but could not use them on the ships. It is a problem to make them adhere to the plate. In addition, it is not easy to tell when they are properly attached. We found that they break down very easily under ship trial conditions and that the output from the strain gages is comparatively low. It is difficult to get reproducible results.

D. E. WEISS, NARC: I wonder if Mr. Pausey could amplify on the preference for the velocity type of pickup rather than the accelerometer or displacement type?

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J. PAUSEY: We found that, in the first place, if you consider displacement and acceleration in ships, you must work over quite wide ranges. Displacements may vary from .001 inch up to several inches. Accelerations may range (in the case of whipping) from 2 or 3 g to several hundred g, and it is difficult to get these two ends of the scale on one record. With velocity, you are working in a smaller range. The low end may be down to 1 foot per second, but you seldom get more than 20 feet per second. It is possible to get all the velocity-time curve on one record without the low or high-frequency components being lost. We do find that from velocity records we can obtain acceleration from the initial slope of the curve, which is the important acceleration as regards shock. There is the danger, in using an accelerometer, that it measures the higher frequency vibrations associated with a very small displacement, which is not particularly important from our shock record point of view.

M. L. HENNOCH, BuShips: In a recent copy of a report on the thirty-ninth meeting of the Admiralty Shock Committee, I read that you are making measurements on masts. A statement was made about using accelerometers for that purpose. The matter was under consideration at that time. Have any instruments been worked on for making the measurements?

J. PAUSEY: I don't remember the report.

J. E. SHAW, R.N.S.S: For some future trials, we are planning to make measurements on motions of masts. I believe there were statements in there about considering the use of accelerometers for the measurements, but the matter was not completely looked into at that time.

M. L. HENNOCH: Additional consideration is to be given the matter, then, and definite instrumentations worked out?

J. E. SHAW: No definite instrumentation has yet been decided upon. The point you read was in connection with masses on deck or on the masts, which were to simulate radar gear. There you get an excursion in space of several inches, and the ordinary type of velocity meter would not cope with that, as it bottoms after a matter of a few inches. Consideration is being given to different methods of recording. At the time, accelerometers were the only answer, but so far we have not decided what we will use.

J. PAUSEY: That particular trial has not started yet. It is still in the planning stages.

I. VIGNESS, NRL: In using multi-conductor cables to carry signals from the test ship to the laboratory ship, do you have any cross-talk or interference between channels for either low-impedance sources or high-impedance sources?

J. PAUSEY: We have not used wire strain gages except with individual cables.

J. T. MULLER, BTL: How long does the velocity pulse last? How long before it comes back to zero?

J. PAUSEY: You can record the velocity over a period of seconds, but the important initial effect probably takes place well within 20 milliseconds.

J. T. MULLER: How does it return-- sharply or slowly?

J. PAUSEY: Generally speaking, there are two forms of shock waves. One of them approximates a cosine curve with a sharp rise and then a damped wave returning to zero. It is difficult to say when it does return to zero, because there is motion of the mass in the velocity meter due to its own springs. For the purposes of shock, it is that initial part of the record which is the important part.

J. T. MULLER: Can you give some idea of the length of time it takes to reach the maximum velocity?

J. PAUSEY: It varies, on different parts of the ship, from 2 to 3 milliseconds up to about 10 milliseconds and, in some exceptional cases, 20 milliseconds.

J. E. SHAW: As I understand it, you want to know how quickly these excitations are damped out in different parts of the shock. The graph (Figure 13) represents velocity against time. On the hull or shell plating disturbances are damped out after a very few cycles. There is a very rapid rise (sometimes under 1 millisecond) followed by a more or less damped oscillation. When dealing with the item of machinery on the hull, as Mr. Pausey mentioned we got a curve resembling a damped sine wave, the time of rise being anything between 2 milliseconds and about 7 or 8 milliseconds depending upon a number of factors such as how the machinery was mounted, thickness of plating, etc. Then, going on to the bulkheads, the rise was still slower until, when working with the decks, one can get anything up to about 20 milliseconds before reaching maximum

value of velocity. The characteristics on the machinery, the bulkheads, and on the decks are generally damped out after about 10 to 20 cycles.

S. P. THOMPSON, NRL: Referring to the errors engendered by making the resonant frequency of a seismic instrument higher than is usual, it would seem that, since a mechanical system of that type is analogous to a tuned circuit, it should be possible to take a circuit and, by suitably arranging its parameters (including those determining damping), to use it as a calculating machine to straighten out both the amplitudes and the phases of the velocity meter record. Have the British considered this proposition at all?

J. PAUSEY: We have considered methods of correction by electrical and mechanical means, but we haven't arrived at the answer we want yet.

D. C. KENNARD, AMC: You mentioned that you use cathode-ray recorders in measuring shock. Have you tried the magnetic galvanometer recorder?

J. PAUSEY: No. We have stuck solely to cathode-ray oscillographs.

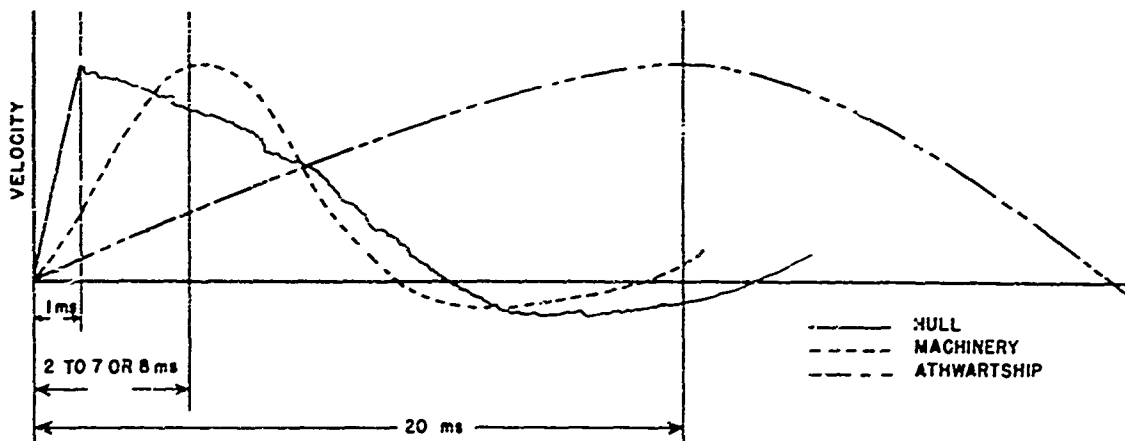


Figure 13

APPENDIX

Let S = position of the meter housing
 X_1 = position of supported mass (m)
 k = constant of the spring
 a = viscous constant of system
 e = output voltage of the meter

The equation of motion is given by the relation

$$m\ddot{X}_1 = k(S - X_1) + a(\dot{S} - \dot{X}_1), \text{ or}$$

$$\ddot{X}_1 = \frac{k}{m}(S - X_1) + \frac{a}{m}(\dot{S} - \dot{X}_1) \quad (1)$$

The voltage generated in the coil is given by

$$e = K(\dot{S} - \dot{X}_1) \quad (2)$$

where K is a proportionality constant.

The variable X_1 can be eliminated between equations (1) and (2) giving,

$$\ddot{S} = \frac{1}{K}(\dot{e} + \frac{a}{m}e + \frac{k}{m} \int e \, dt), \text{ or}$$

$$\ddot{S} = \frac{1}{K}(\dot{e} + 2ce + \omega_0^2 \int e \, dt) \quad (3)$$

where c is the damping factor and ω_0 is the undamped resonant frequency of the system when the case is still.

If equation (3) is integrated once, it follows that

$$\dot{S} = \frac{1}{K}(e + 2c \int e \, dt + \omega_0^2 \iint e \, dt) \quad (4)$$

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Thus, a voltage e' equal to the absolute velocity of the instrument can be obtained, provided

$$s' = \frac{1}{K'}(e + 2c \int e \, dt + \omega_0^2 \int \int e \, dt) \quad (5)$$

where K' is numerically equal to K .

Obviously, e' can be generated by combining the observed voltage e with the proper proportions of its first and second integral. If c is very small, this term can be neglected. If a steady-state motion exists, then $e = E_0 \sin(\omega t + \phi)$ and the output voltage of the correcting networks is

$$e' = \frac{E_0}{K} \sin(\omega t + \phi) \left(1 - \frac{\omega_0^2}{\omega^2}\right). \quad (6)$$

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SIMILARITIES AND DIFFERENCES IN INSTRUMENTATION FOR ORDNANCE FIELD TESTS

By

D. E. Mariow, NOL

I have been asked to compare the instrumentation of ordnance field trials with the instrumentation of ship damage trials, such as Mr. Pausey has described.

First, as to the similarities: Our interest in the effects of explosions on ships has been entirely an interest in economy. To the ordnance engineer a ship is simply one class of target, and all targets are objects to be destroyed with the maximum economy of explosives. We have been largely content, therefore, to obtain the advice of our ship designers as to the response of ship structures to these impulsive explosive loads and have limited our participation in ship damage trials to studies of the phenomena associated with the explosion in water and, in particular, to the modifications to the theory which would be required to account for the discontinuity in the fluid medium presented by the presence of an air-backed hull. In order to obtain field data on this and other points, we have obtained an ex-patrol craft (the EPCS 1413) and have specially equipped her for the accurate measurement of pressure-time data from large underwater explosions in the open sea. Figure 1 shows the 1413 tied to her dock at the Naval Gun Factory. She serves as a floating recording station very comparable to the ENSLEIGH described by Mr.

Pausey. Figure 2 shows her recording room with six oscillographic recording stations equipped with high-speed, rotating-drum cameras. You can see that except for slight differences in design, the 1413 and the ENSLEIGH serve almost identical purposes.

Now, as to the differences in instrumentation: Most ordnance field trials require instruments and techniques which differ quite radically from those just described. I have mentioned in a previous paper (published in Shock and Vibration Bulletin No. 5) that ordnance shock problems are characterized by the long duration of the shock, and I indicated at that time that these shocks must be endured for distances of 5 to 100 feet. This characteristic of ordnance shocks renders the use of velocity meters quite impractical, and we have concentrated, therefore, upon the development of accelerometers based upon the measurement of either the elastic or plastic strain of some portion of the vehicle being tested. In most cases, of course, it has been most convenient to build a special strain indicating instrument for use in the vehicle. At various times, we have exploited the innumerable forms of crusher gages, and we have used piezoelectric, resistance wire, and capacitance gages as well--the choice be-

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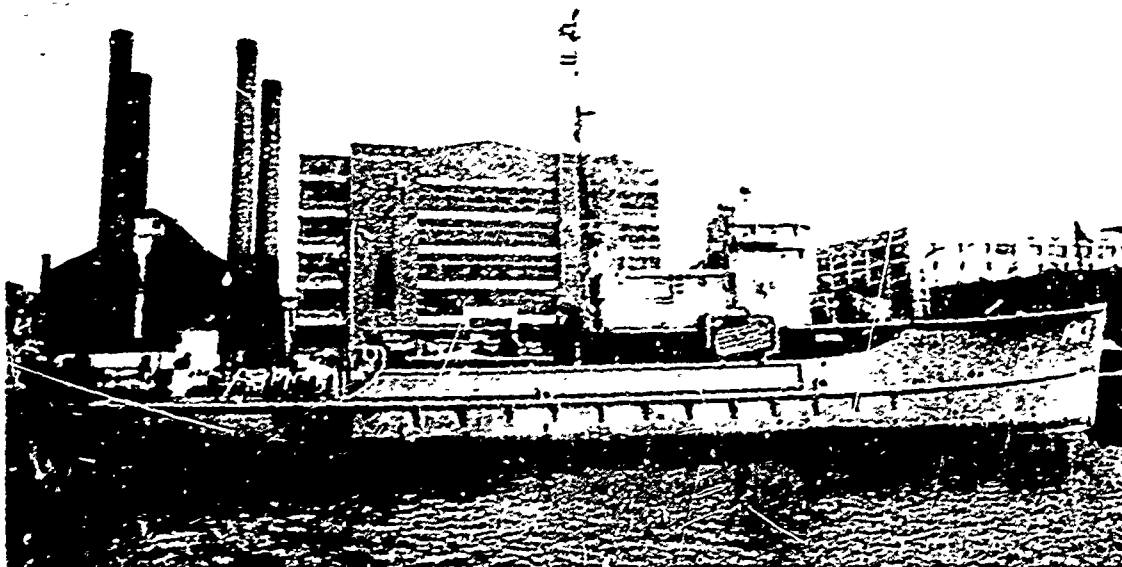


Fig. 1 The ETCS 1413

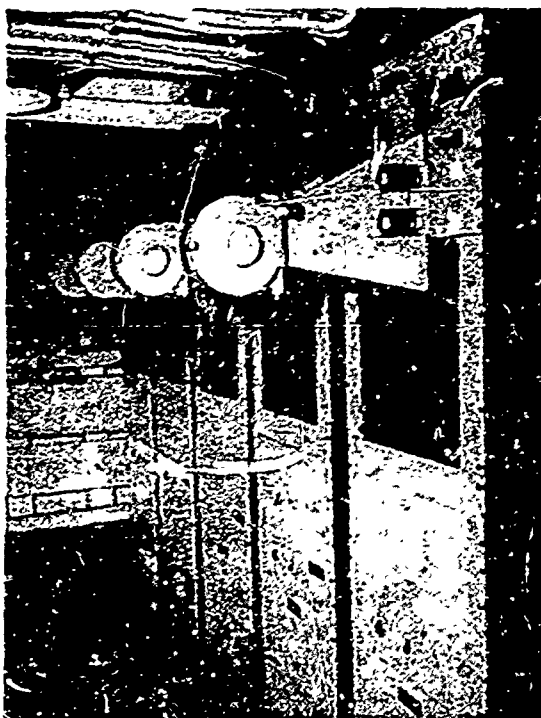


Fig. 2 Recording Room

tween them usually being dictated by the requirement of the transmission and/or the recording system.

In all such measurements, it has been found necessary to study the theoretical aspects of the measurements very carefully, for an improper choice of the accelerometer for a particular measurement can render the experiment worthless. In particular, accelerometer measurements are susceptible to variations in calibration techniques, and we have expended great care in the checking of one accelerometer against another in order to eliminate, as much as possible, the various sources of error.

Figure 3 shows six types of accelerometer principles which are based on either the plastic or elastic deformation of a recording element. These devices are limited to recording peak accelerations and, even then, must be very carefully used in order to obtain reliable indication. Figure 4 shows four accelerometers also based upon the elastic deformation of the

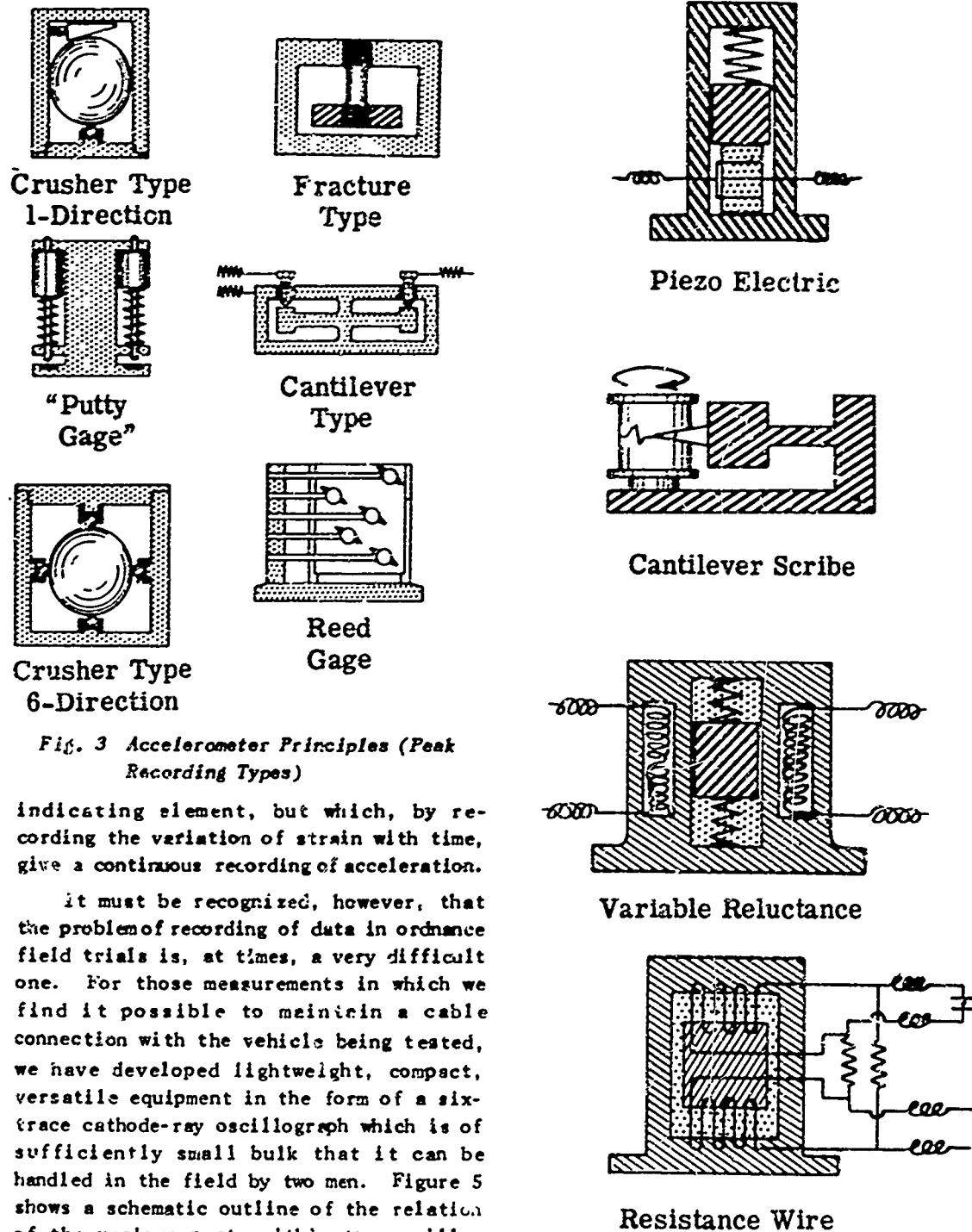


Fig. 3 Accelerometer Principles (Peak Recording Types)

indicating element, but which, by recording the variation of strain with time, give a continuous recording of acceleration.

It must be recognized, however, that the problem of recording of data in ordnance field trials is, at times, a very difficult one. For those measurements in which we find it possible to maintain a cable connection with the vehicle being tested, we have developed lightweight, compact, versatile equipment in the form of a six-trace cathode-ray oscillograph which is of sufficiently small bulk that it can be handled in the field by two men. Figure 5 shows a schematic outline of the relation of the various parts within the oscillograph, and Figure 6 shows a somewhat exploded view of one of the early models. It will be seen that this instrument is ideally suited to the recording of phenomena which vary with time in field trials.

Fig. 4 Accelerometer Principles (Continuous Recording Types)

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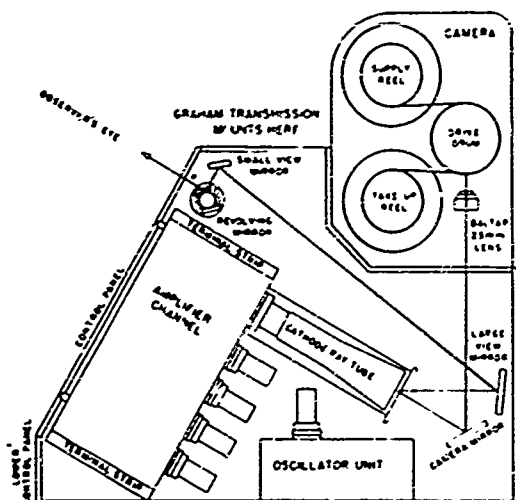


Fig. 5 NOL 5-Trace CRO Type 1B Layout of Main Frame

However, in many of our measurements, we are unable to maintain a cable connection to the vehicle. To provide for such cases, we have developed a line of compact, self-contained, internal recorders which are mounted inside the vehicle and which must be designed to record the electrical impulse from the detection instrument faithfully, even though the recorder itself is undergoing the shocks. This is of course, a problem which is never completely solved, and the balance between signal and noise is always a delicate one.

Typical of these instruments is one shown in Figure 7. This is a cellulose-tape recording accelerometer in which the acceleration-time curve is engraved upon a cellulose tape by a cantilevered mass and scribe. This instrument is somewhat insensitive and of fairly low frequency response, but it has been developed to the point where the spring-driven drum will maintain a continuous speed throughout the acceleration period; hence, the device as a whole is capable of giving usable records for many applications.

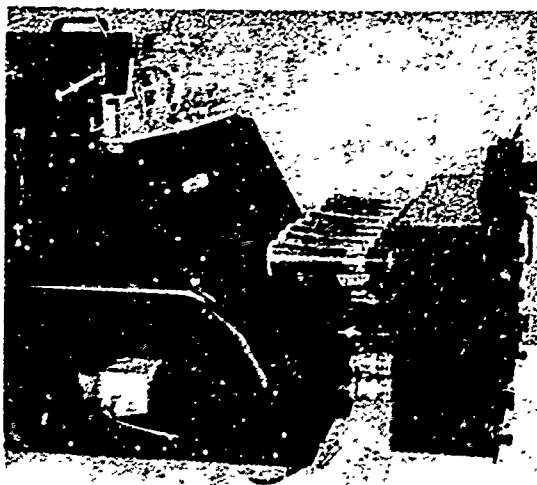


Fig. 6 Early Model Oscillograph

Next, we have Figure 8, which shows the complete assembly of a three channel oscillographic recorder. It is designed to be self-contained, so that the entire unit can be placed in a mine case or bomb for the purpose of measuring accelerations on impact with the water surface. There are three crystal accelerometer elements which feed a signal to an oscillographic camera, the whole being powered from the battery box.

Figure 9 shows a schematic diagram of the recording camera of the previous set-up.

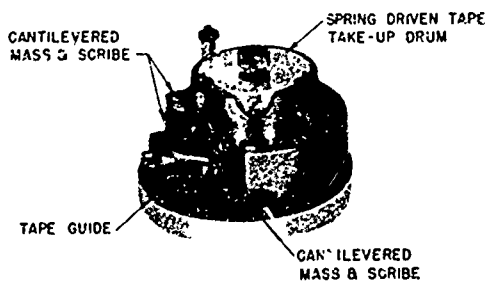


Fig. 7 NOL 3-Directional Tape Recording Accelerometer

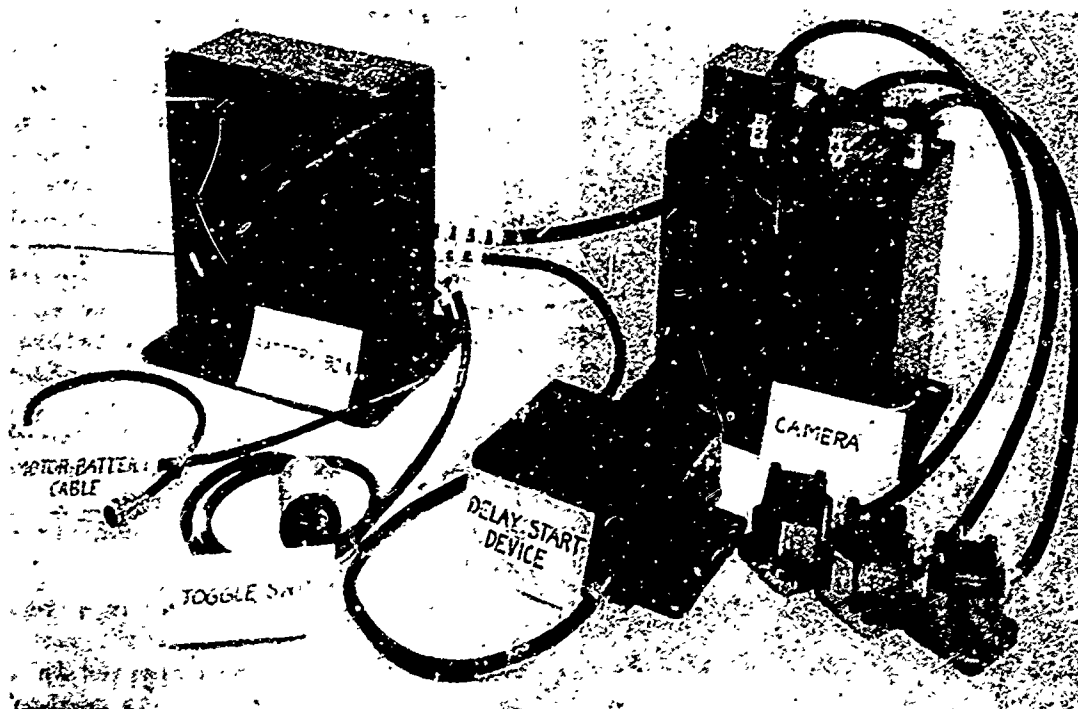


Fig. 8 Assembly of 3-Channel Oscillograph Recorder

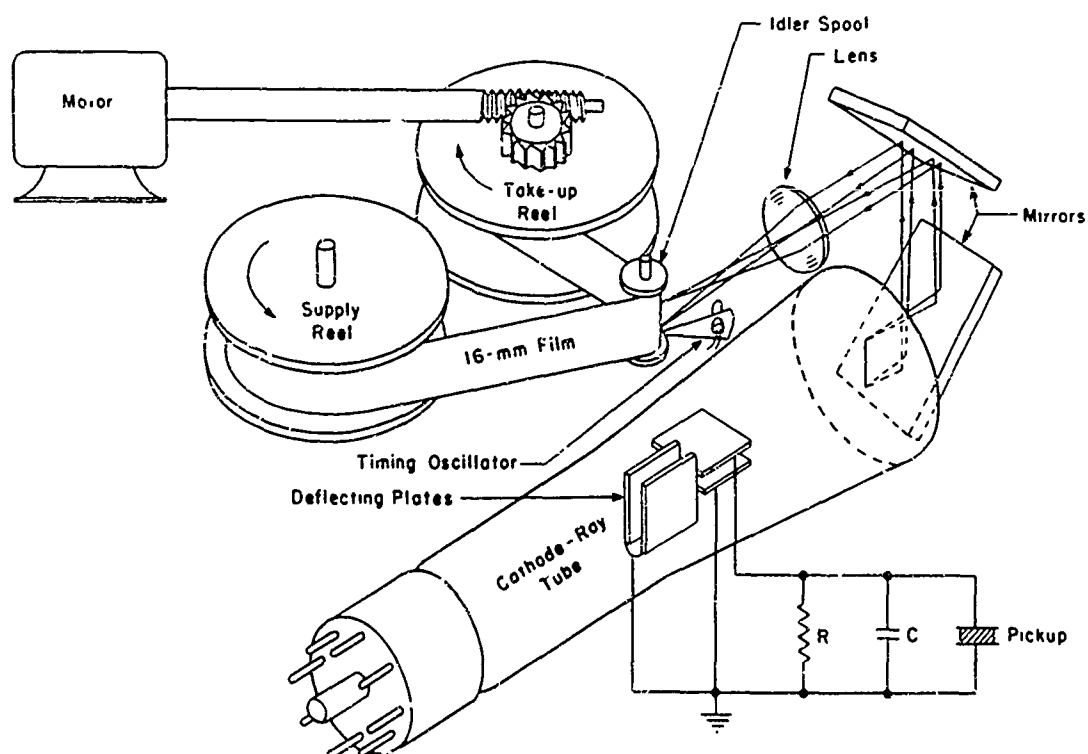


Fig. 9 Schematic Diagram of Recording Accelerometer

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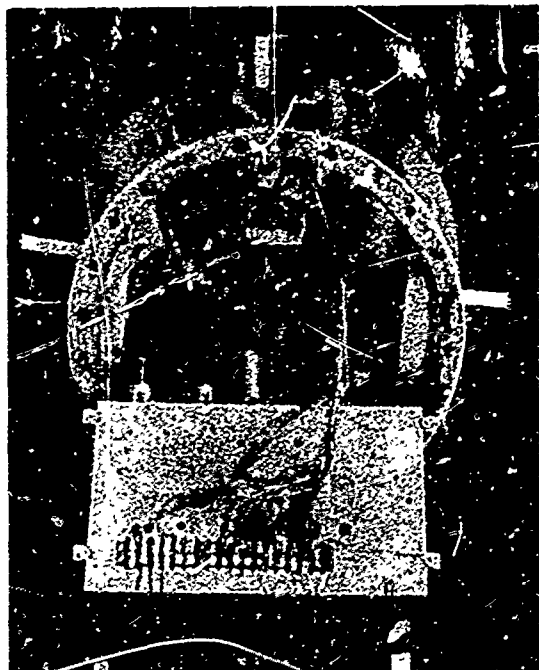


Fig. 10 Preliminary Telemetering Equipment for Measuring Parachute

It will be seen that the optical distances are largely obtained from mirrors and that the cathode-ray tube, as mounted, must take the full strength of the acceleration without causing deviations in the cathode-ray beam. This has been accomplished with a fair degree of success. The cathode-ray tubes have been specially strengthened with added internal elements and, as a whole, the device is capable of recording an acceleration-time pattern without serious noise levels at accelerations below about 300 g.

In spite of the success with which internal recorders have been used, the Laboratory is not completely satisfied with this approach, and in many cases, since these instruments and recorders are not adequate to the situation, we make use of one other very powerful tool. The combination of detecting instruments in the vehicle, data transmission by telemetering techniques, and recording at a ground station has solved so many of our

difficulties in recent months that we are leaning more and more heavily upon it.

A fairly recent example was the measurement of the opening load in parachutes when launched from aircraft at high speed. Figure 10 shows the rear end of a mine case with its telemetering equipment installed and the antenna encircling the instrument compartment, while Figure 11 shows sensitive elements mounted in each of the shroud lines of the parachute just before it is packed into its case. Upon opening, these elements respond to the strain in the parachute shroud lines, and the data are transmitted by a frequency-modulated telemetering system to a recording station on the ground where the signal is demodulated and recorded.

Those of you who have used telemetering methods will readily recognize the great advantages that can be obtained in the instrumentation of field trials by the use of these techniques. Let me now point out a new field of usefulness which we have successfully exploited in recent months. We are now using telemetering techniques in the field in trials of underwater ordnance. During the conduct of recent tests at Hiwassee Dam, a freshwater lake in the Tennessee Valley, we have telemetered data from an antisubmarine weapon and have observed the time sequence of events during the passage of the weapon from air into water and into the proximity of its intended target. There is every reason to believe, at the present time, that our dependence on the vagaries of internal recorders is reaching an end.

Figure 12 is a reproduction of one of the traces from this underwater telemetering equipment. You will notice the various stages of behavior of the weapon from launching to impact with the recovery net, and for comparison purposes, there is presented an oscillograph trace showing the signal output of the detection device during each of those stages.

To summarize: Where the ordnance engineer can maintain cable connections

with the device being tested, the techniques used are quite similar to those of ship damage trials. The major difference lies in our requirement for accelerometers rather than for velocity meters, and this, in turn, is enforced by the long duration shocks encountered by ordnance and by the small space in which recording instruments can be placed.

However, when cable contact with the vehicle cannot be maintained, we have in the past depended heavily upon the use of internal recorders and have expended substantial effort in their development. At the present time our emphasis is shifting rapidly to the use of telemetering methods. These have already proved practical and useful for trials of airborne weapons and recent developments indicate that equal success may be obtained for underwater trials as well.

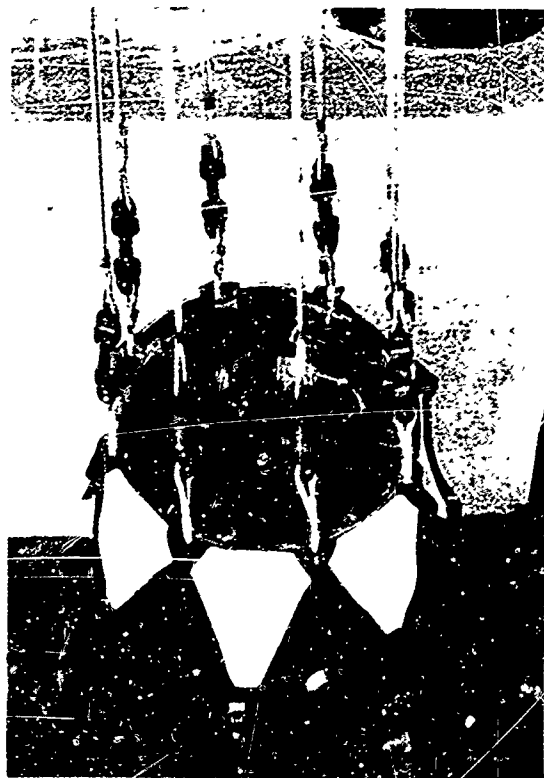


Fig. 11 Elements Mounted in Parachute Shroud Lines

DISCUSSION

J. PAUSEY, R.N.S.S: I am interested in the possibilities of telemetering and feel that we may have to use something of the same technique in some of our trials. I think it will become necessary. The question of self-recording instruments also is of great interest to me. I would like to ask Mr. Marlowe one question about the instrument which used the crystal pile. Do you get sufficient output from that accelerometer direct?

D. E. MARLOWE, NOL: Yes, the output of the crystal was applied directly to the plates of the C.R.O. There was no intermediate amplification.

J. PAUSEY: It must have been quite a large output.

D. E. MARLOWE: It was a fair-sized crystal stack. The overall size of the instrument was almost two inches on a side.

J. PAUSEY: Mr. Marlowe, would you say you are doing any work on telemetering in salt water?

D. E. MARLOWE: I thought I had slipped by that point fast enough so no one would notice it. In due honesty, I felt it was necessary to mention the fact that we were working in a fresh water lake. Attenuation in salt water is up by a factor of 300. We are seriously considering the possibility that, for the ranges that are necessary for that sort of work, tele-

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metering in salt water may be possible. There are two possibilities. One is to increase by this factor of 300, or more, the power output of these subminiature tube circuits (there have been some signs that this may be done). The other is that we have a dim idea (for which, unfortunately, Maxwell's equations don't offer too much hope) that we can beat the game by the use of pulse or pulse coded techniques. Whether the increase of energy that we can put into the water by pulsing will be sufficient to take care of the fact that the pulse is of higher frequency than the

basic signal, we don't know, but perhaps by use of pulse coded techniques, we can make some progress in that direction.

E. KLEIN, NRL: Was the depth of the water a factor?

D. E. MARLOX: No. We are fortunate in having a quiet lake in which to work. We can string a large antenna arrangement. In this particular instance, at no time is the weapon at a distance greater than 100 yards from the nearest antenna, so that the transmission usually takes place over less than 100 yards.

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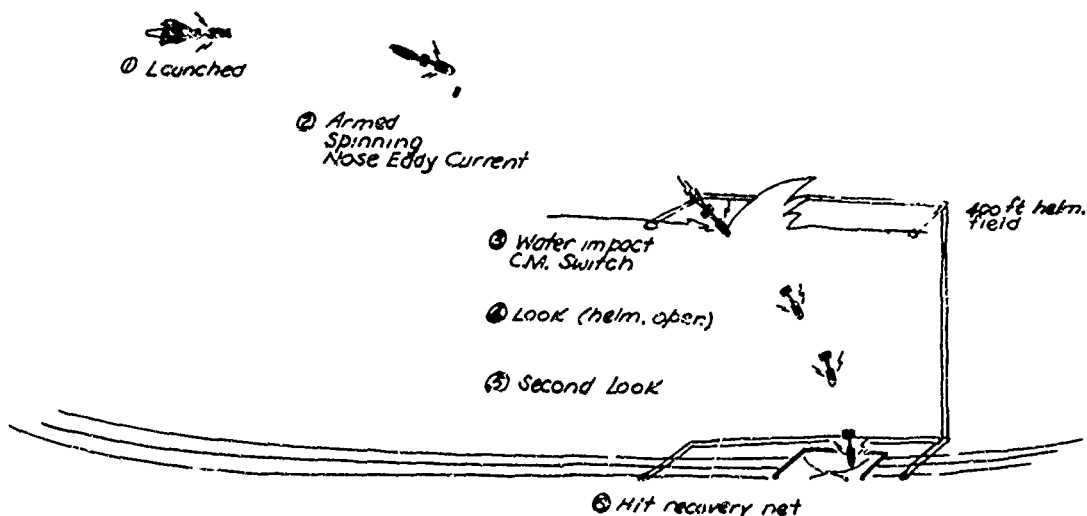
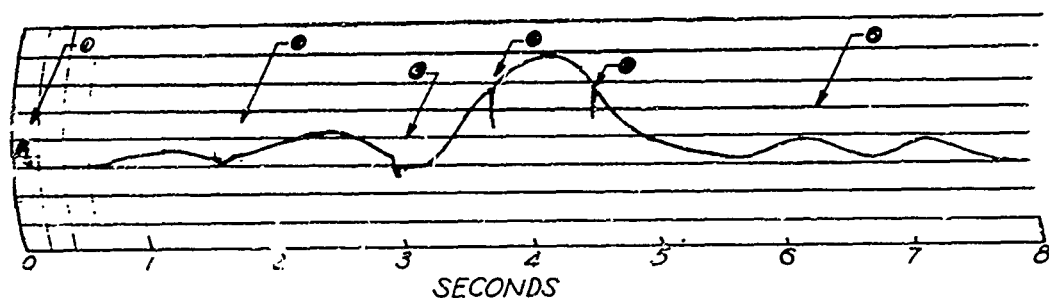


Fig. 12 FM Radio Frequency Telemetry for Weapon A

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CONTRASTING PROCEDURES FOR AIRCRAFT

By

Christian G. Weeber, NANC, NAES

GENERAL

In general, the requirements and procedures for instrumenting aircraft structures and equipment in performing laboratory and flight test investigations are governed, to a great extent, by several factors peculiar to the field of aircraft engineering. The factors of weight and compactness in aircraft construction impose very definite limitations on the size and weight of equipment which can be utilized for test purposes. In addition, the lightness and flexibility of aircraft structures necessitates the use of pick-up units whose size and mass will not have a significant effect upon the measurement of such structural characteristics as strain, deflection, acceleration, etc. For flight test work, test equipment must be rugged and reliable and function satisfactorily under conditions resulting from wide fluctuations in atmospheric temperatures and pressures, engine and aerodynamic disturbances or vibrations, rapid variations in frequency and magnitude of applied "g" forces, and changing attitudes of the aircraft. Test equipment must also be capable of withstanding the impact forces and accelerations experienced during catapult and arrested landing operations. Since aircraft structures are designed within very close margins of

safety, it is essential that test equipment and instruments possess a high degree of accuracy particularly where laboratory or flight tests are being conducted in "step" fashion under conditions of increasing severity.

In performing catapult and arrested landing tests, structural flight tests, and vibration and drop tests on full-scale aircraft and dynamic tests of aircraft equipment, it is generally necessary that a variety of physical quantities be measured and recorded simultaneously in order that a complete analysis can be made of the operation or test performed. Although a number of instruments are available for use in aircraft testing, the instrument most commonly utilized for obtaining test data is the variable resistance strain gage as used in the conventional bridge circuit with associated amplifying equipment and multi-galvanometer recording oscillographs. Because of its size and weight and corresponding small effect upon the characteristics of the structures or instruments to which it has been applied or adapted, the strain gage has been employed for a wide variety of uses in dynamic tests of aircraft for the measurement of acceleration, velocity, displacement, temperature, pressure, and other quantities.

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In all test work, care must be exercised that the gages have been properly bonded and adequately protected against damage. At the time laboratory calibrations are conducted on instrumented aircraft, shunt resistance calibrations are also made on the test recording equipment. This calibrates all components of the measuring system except the gages. These resistance calibrations can be very readily repeated, at any time during the course of a test program and corrections made, if necessary, for any changes in recording equipment characteristics since the original laboratory calibration. This feature is particularly important in test work extending over a long period, since automatic resistance calibrations can be made immediately before and after each flight maneuver or test performed, thereby permitting a close check on equipment calibration and eliminating the necessity of repeating laboratory calibrations on the complete aircraft at frequent intervals.

An attempt will be made to show some of the techniques and procedures utilized in the instrumentation and test of full-scale aircraft and aircraft equipment by describing briefly a few typical dynamic tests performed. With the possible exception of crash landing investigations, it should be noted that in comparison with shock tests of marine vessels the dynamic phenomena measured during aircraft tests generally occurs over a greater time period; roughly, from .05 to 0.2 of a second or longer.

AIRCRAFT DROP TESTS

During carrier evaluation tests of a twin-engined Navy fighter, the wing center sections of seven out of eight airplanes brought aboard were damaged during landing impact. The majority of the landings made were unsymmetrical, i.e., either the nose gear or one main gear initially contacted the deck. Figure 1 shows the most severe failure which occurred during these landings. A preliminary investigation of the cause of these failures indicated that the landing gear reactions combined with the vertical

inertia forces of the projecting engine mass imposed excessive torsional loads on the wing structure.

To investigate and determine the cause of the failures more completely, this model airplane was subjected to a series of instrumented drop tests in the laboratory. The test set-up is shown on Figure 2.

Strain gages were mounted on the upper and lower surfaces of each wing panel near the root to obtain data on the magnitude of the torsional loads imposed on the wing structure during the drop tests. Gages were also placed on each engine mount structure to determine the magnitude of the torsional loads imposed on the wing by the vertical inertia forces of the engine mass. The gage installations were calibrated by applying known vertical loads to each engine propeller shaft and calculating the total torsional loads applied to the wing structure. The calibration loads were balanced by the reactions on the airplane landing gear. Dynamic reaction platforms were installed under each landing wheel to obtain data on the vertical load-time history of each gear during the drop tests. Each of these triangular-shaped loading platforms weighs about 1000 pounds and is supported by three tubular steel pedestals on which strain gages have been mounted. The gages are wired in such a manner that they respond only to column loads on the pedestals or loads applied normal to the platform surface. In addition to the foregoing instrumentation, NAES strain-gage accelerometers (beam type) having a natural frequency of 23 cps were located at the c.g. and in the empennage of the airplane.

During the investigation, the airplane was subjected to a series of drop tests of increasing severity simulating both symmetrical and unsymmetrical landing conditions. In the latter stages of the tests, the airplane was dropped in such an attitude that one main gear received the initial landing impact, the nose gear

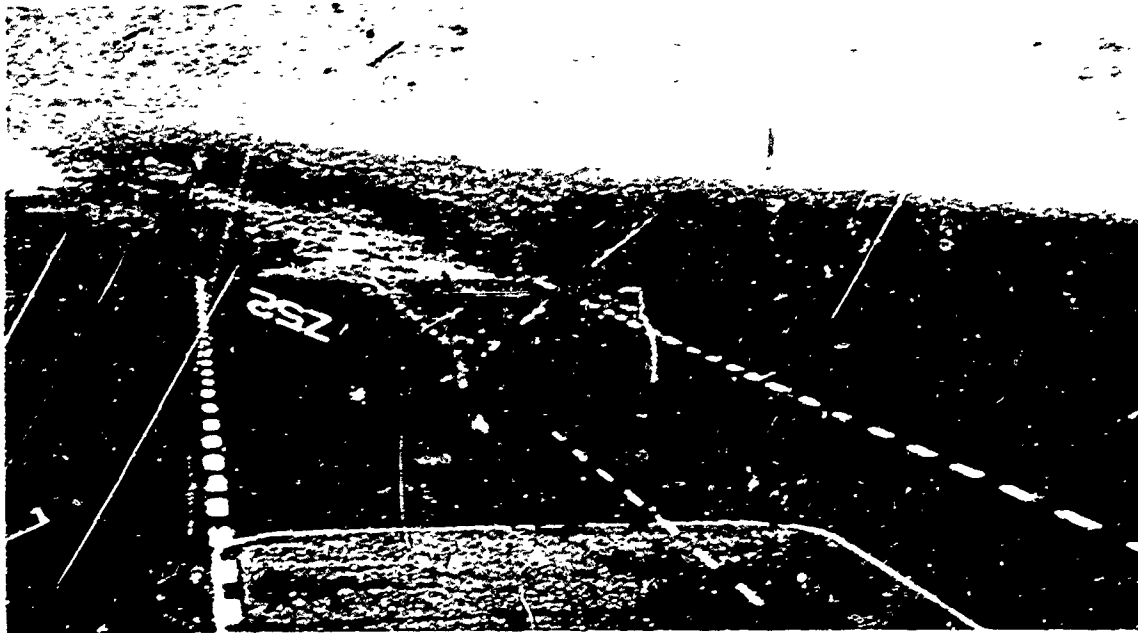


Figure 1

and other main gear subsequently contacting in that order. During these tests, as shown in Figure 1, each landing wheel was prespun so as to have a peripheral speed of 90 mph upon impact in order to simulate the actual drag loads imposed on the gear during landing.

Figure 3 shows a typical oscillogram of the data recorded during these drop tests and Figure 4 shows the duplication of the carrier failure obtained in the laboratory.

EJECTION SEAT TESTS

In the design and development of a pilot's ejection seat and personnel catapult for emergency escape from high-speed aircraft, extensive ground and flight tests have been conducted. The 110-foot ejection seat test tower located at the NAMC has been used principally for the development and test of a suitable powder charge catapult, for the measurement of ejection loads and accelerations, and for the investigation of human tolerances to various magnitudes and rates of application of forces experienced during ejection.

A 40-inch telescoping aluminum catapult weighing 8 pounds and containing a powder cartridge is attached to the seat back and to the base of the tower structure between the guide rails. Upon detonation of the cartridge by the occupant, the energy released by the burning powder imparts an ejection velocity to the seat-man mass of 60 fps in 0.2 second over a 40-inch catapult stroke. The maximum acceleration developed during ejection ranges from 16 to 19 g's.

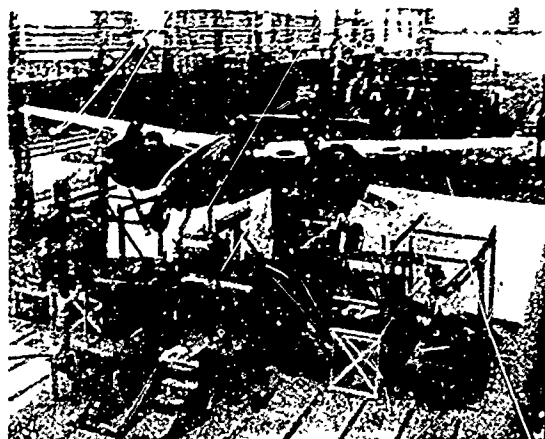


Figure 2

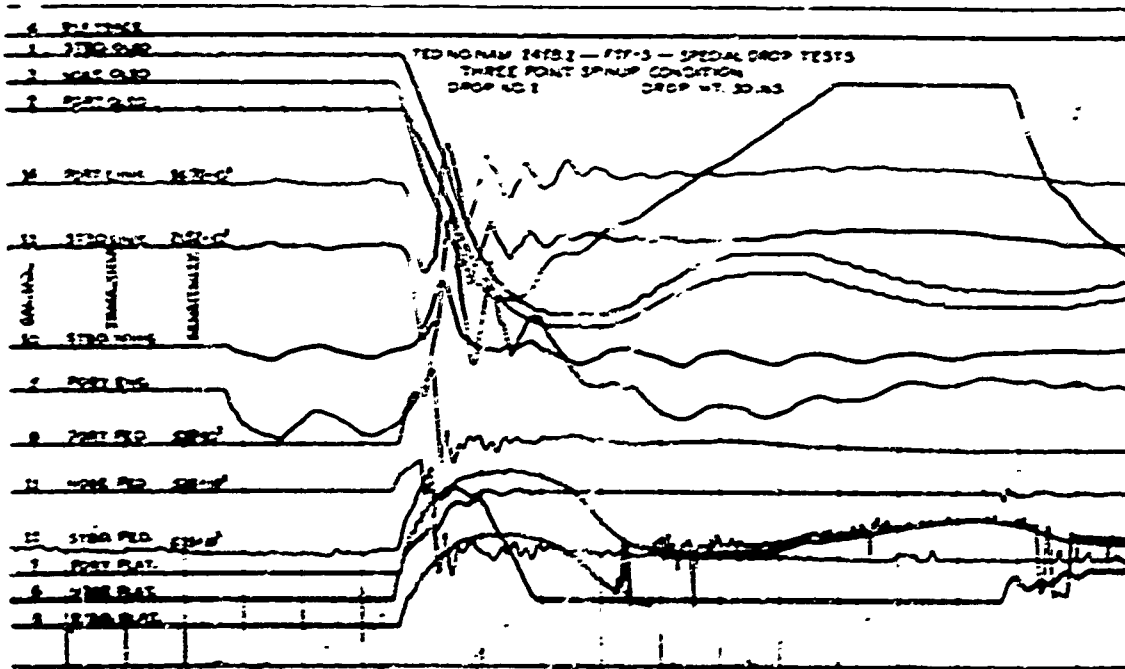
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Figure 3

Figure 5 shows the instrumentation used on the subject during the performance of tower tests. Statham strain-gage accelerometers having a natural frequency of 500 cps and 0.7 critical damping are mounted on the subjects head, shoulder, and hip. A similar accelerometer is mounted on the seat structure. No amplifiers are used with these accelerometers, the outputs being recorded directly by a

consolidated oscillograph equipped with high-sensitivity galvanometers.

The ejection velocity is determined by means of a fixed coil located on the side of the seat structure. The coil passes over stationary Alnico magnets spaced at 2-inch intervals along the tower track. The current induced in the coil by each successive magnet momentarily deflects the galvanometer element causing a "blip" in the oscillograph recording trace. Having time and distance, the velocities can be readily computed.

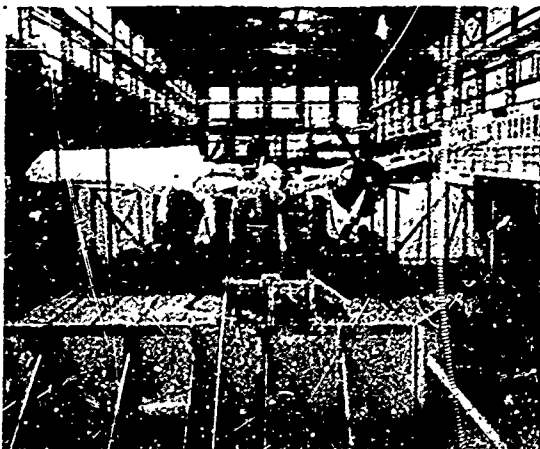


Figure 4

A measurement of the internal pressures developed in the catapult during ejection is obtained by means of strain gages mounted circumferentially on a copper-beryllium tube having one end closed and connected to the catapult chamber through a smaller diameter tube. The tube is packed with silicone grease so that the initial volume of the catapult will not be significantly altered. The grease also insulates the gages from the high internal catapult temperatures developed during ejection.

A typical oscillogram obtained during tests on the ejection seat tower is shown on Figure 6.

Figures 7 and 8 show the instrumented dummy used for flight ejection tests. Three NAES bonded strain-gage accelerometers (5- π type) having a natural frequency of 25 cps and a ± 20 g range are mounted along the vertical, fore and aft, and lateral axes of the dummy. A Heiland type 401R oscillograph equipped with high-sensitivity, Type A galvanometers and a power supply are mounted in the chest cavity of the dummy. The oscillograph is started by remote control immediately before ejection and acceleration records are obtained on the seat and dummy during the full ejection sequence, including the operation of the seat parachutes. A self-contained, 3-component, mechanically



Figure 5

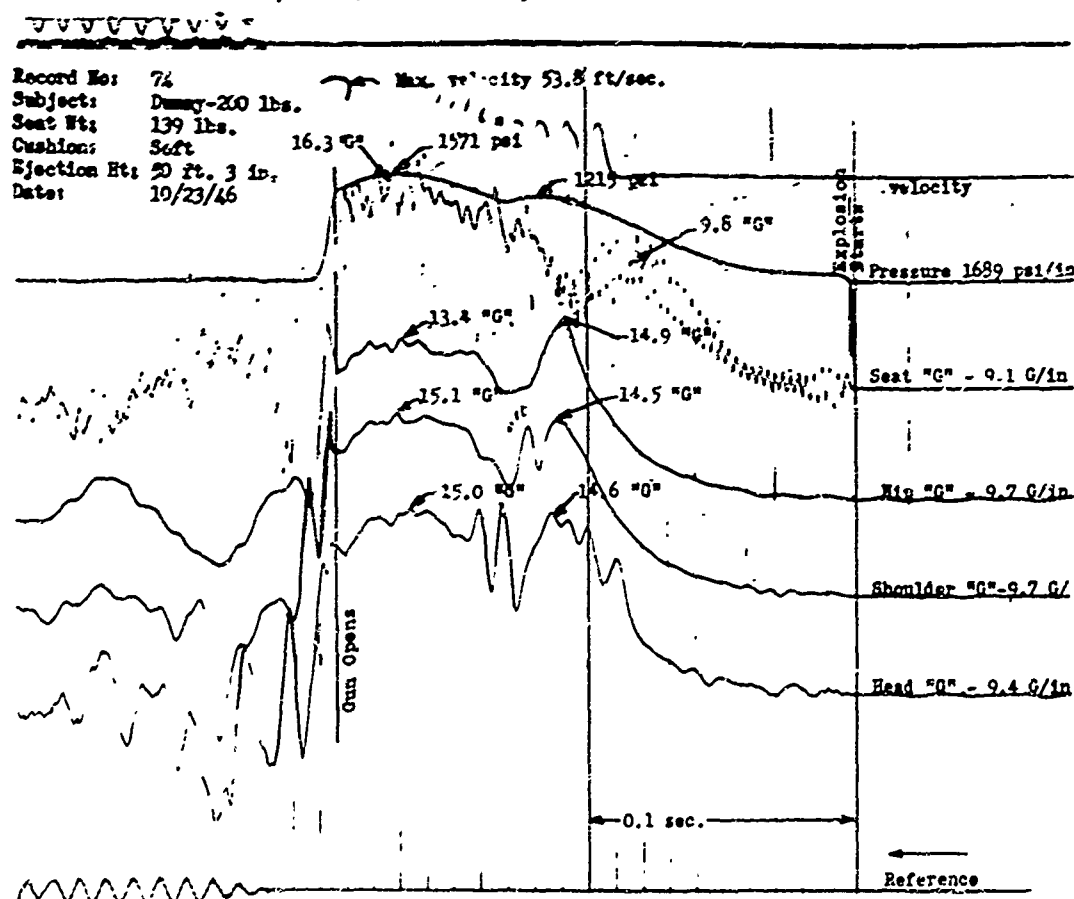


Figure 6

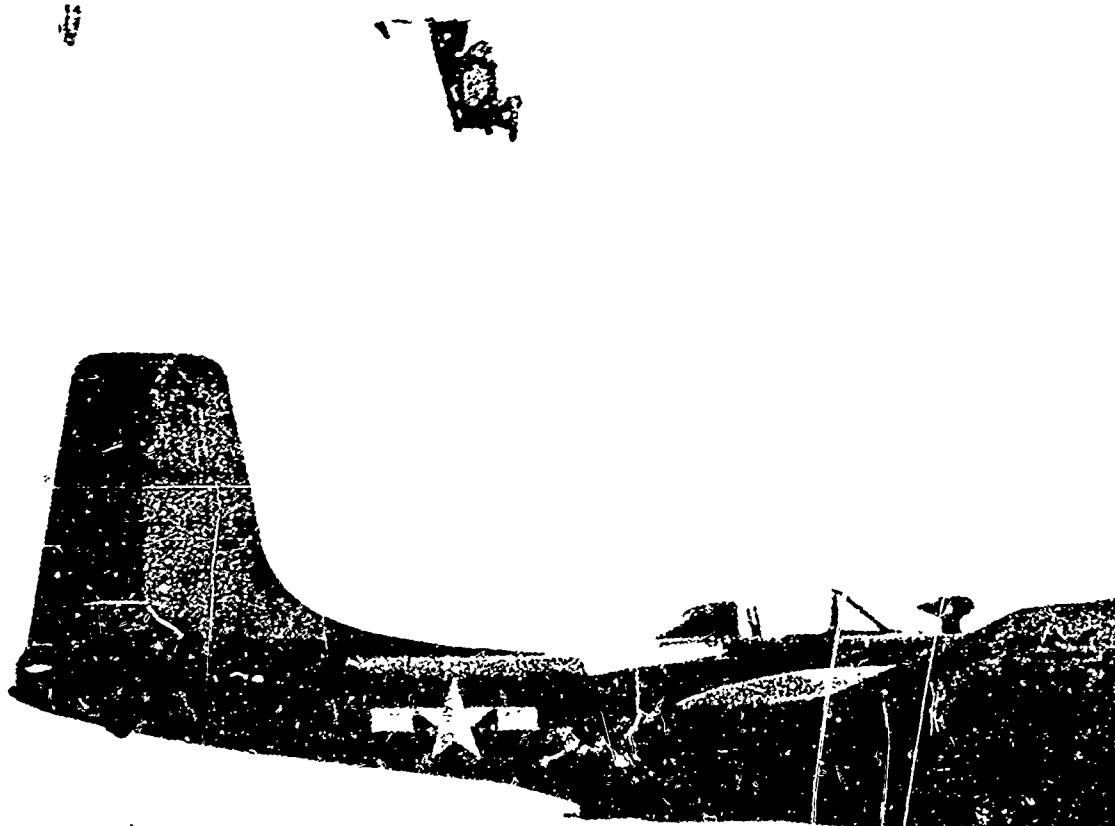
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*Figure 7*

recording accelerometer having a natural frequency of 40 cps and a range of ± 30 g is now undergoing evaluation tests for use in future dummy instrumentation.

IMPACT TESTS

In the development and test of a pilot's seat capable of sustaining 40 g fore-and-aft crash landing loads, occurring in a time period of .05 seconds from impact to peak, dynamic tests were conducted in a drop test machine. The seat and 200-pound dummy were mounted face downward in a rigid jig attached to the drop test car. The car was dropped on a wooden block 20 x 20 inches in cross section, on top of which various grades and thicknesses of rubber pads had been placed to give the desired acceleration-time loading on the seat. The test set-up is shown in Figure 9.

*Figure 8*

During these tests, tension links on which strain gages had been mounted were inserted in the lap and shoulder straps to determine the magnitude and distribution of the loads in the harness. Statham accelerometers, ± 40 g. were mounted at the c.g. of the test car and the dummy. In some of the tests, Bureau of Standards dynamometer rings were inserted in series with the harness strain gage links. When subjected to tension loads these 1-inch diameter rings are permanently elongated. By measuring the minor diameter of the elongated rings, the maximum tension load can be determined from a calibration curve based on static and dynamic laboratory tests. As compared with the strain gage data, however, the maximum harness loads determined from the dynamometer rings were consistently lower. Indications are that the elongation of the ring actually lags the applied tension force, particularly at high rates of load build-up. In addition, there seems to be some erratic elastic recovery of the rings following removal of the load.

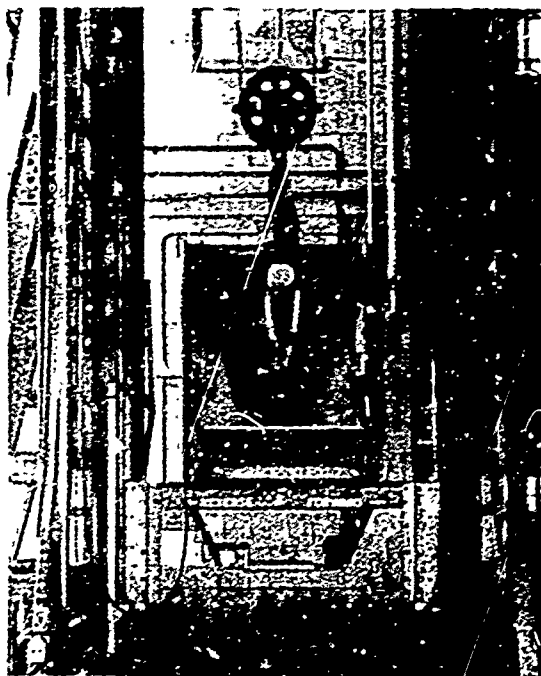


Figure 9

Figure 10 shows an oscillogram obtained during these tests.

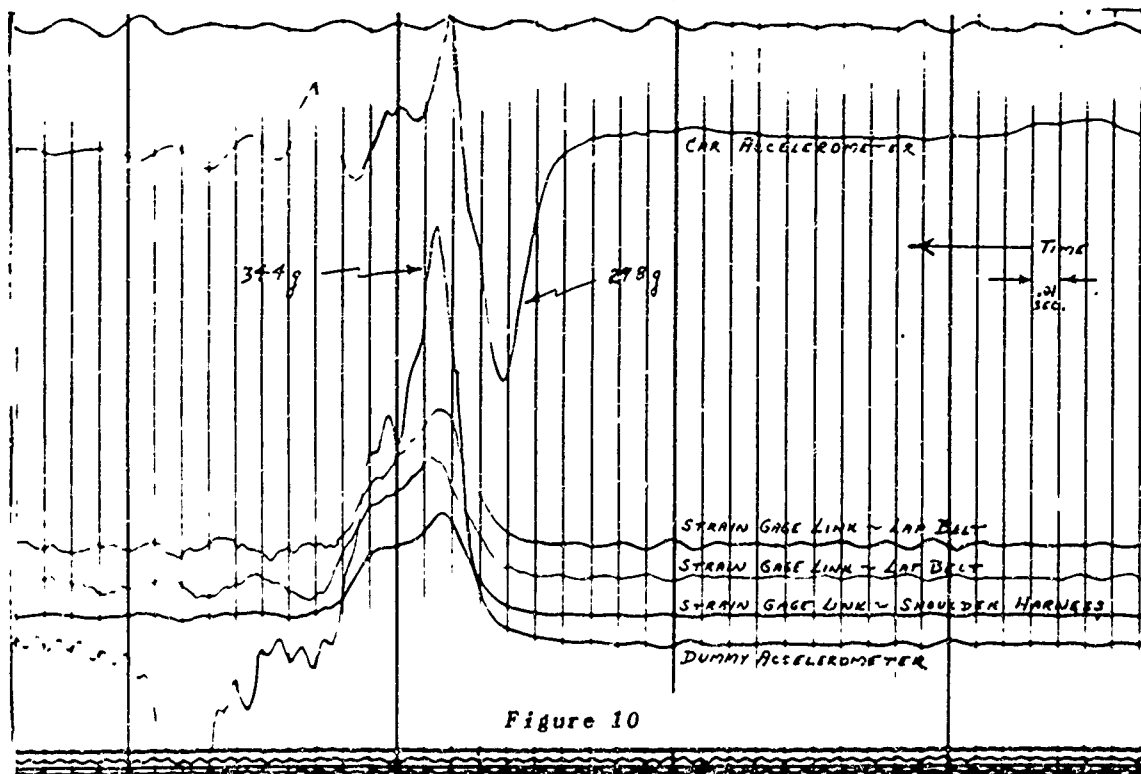


Figure 10

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DISCUSSION

E. KLEIN, NRL: We have discussed similarities and differences of three main types of instruments which were used in field operation--the velocity meter (which is an especially suitable instrument in ships), the accelerometer for ordnance, and the wire strain gage for aircraft.

G. CHERTOCK, DTMB: I would like to ask about the Bureau of Standards rings. What do they measure--acceleration or force--and how is it applied?

C. G. WEEBER, NAMC, NAES: The rings measure the maximum force developed in the seat belting during impact tests. They are inserted in series with the belting. These rings are initially circular. Under load, they are permanently elongated, and by conducting previous laboratory calibrations on similar rings and measuring the minimum diameter after various loads have been applied and relaxed, the approximate magnitude of the loading can be determined. There is some difference, however, in maximum loads measured in this manner, due to apparent differences in the static and dynamic calibrations of the rings with respect to the rate of load application.

G. CHERTOCK: What is the material of the rings?

C. G. WEEBER: I think the rings are made of SAE 4130 steel.

A. E. McPHERSON, NBS: They are made of SAE X4130 magnaflex quality, and the quality control is quite difficult and expensive. The theory is that the static and dynamic calibration should be the same, which we have found to be so up to a rate of loading where .02 of a second was required for reaching peak load. Above that point we don't know, but it seems reasonable that we could go to even higher rates of loading.

W. E. BAKER, LOS ALAMOS SCIENTIFIC LABORATORY, SANDIA BASE BRANCH: What type of recording oscillograph have you found most satisfactory?

C. G. WEEBER: In answering I believe I will call upon Mr. Weiss, who is primarily our instrument man.

D. E. WEISS, NAMC, NAES: Three types of moving coil galvanometer cameras widely used in the aircraft industry are ones manufactured by William Miller Company, Consolidated Engineering, and Heiland Research Corporation. Each has advantages and disadvantages. Miller and Consolidated cameras are usually made with galvanometers numbering from about 6 to 36 units in one camera. The Miller oscillograph has a much better optical system; the resolution of their recording trace is much finer. In general, it is much more suitable for field use than the Consolidated, although not entirely so. Consolidated has available a greater and more useful variety of galvanometers; they make very sensitive galvanometers with a natural frequency of 150 cycles per second, enabling use, with no amplifiers, at applied frequencies as high as 100 cycles per second. These galvanometers are used with DC bridges. The Heiland Research Corporation manufactures a relatively inexpensive, compact six-galvanometer camera. This unit has about the smallest volume per channel but records on paper which is only two inches wide and is devoid of such refinements as automatic record numbering and remote control facilities. There is no way of selecting one over the other--all are good in some respects and deficient in others.

E. KLEIN: In the next Bulletin (No. 8) which is mainly on instrumentation, many of these instruments, including rings, are described.

K. W. JOHNSON, AMC: What type of recorders do you use in fighter aircraft?

C. G. WEEBER: On fighter type airplanes, we have used Miller, Consolidated, and Heiland oscillographs. There is a special problem in instrumentation on fighter type planes--the F4U is a typical example. In that case, all of the radio equipment was removed, and our equipment was mounted behind the pilot's seat. That, as a general rule, is the only available space for installing equipment (in the aft section of the fuselage). The installation of test equipment very often presents difficulties in trying to achieve a specified or satisfactory c.g. location on the airplane for flight tests.

O. D. TERRELL, NTS: Have you investigated the direct effect of shock or acceleration upon the various types of galvanometers?

D. E. WEISS: Galvanometers used during our tests are checked statically that is, the recording oscillograph is placed on all six faces, thus imposing a 1-g load on the galvanometer elements along three axes. If the effects of this static load do not exceed, roughly, .01-inch maximum deflection of the trace, they are considered satisfactory. In flight tests we usually apply the output of fixed resistances directly to the galvanometers and thus determine the response of the galvanometer to the mechanical shock. Usually, by selecting galvanometers on the basis of these two tests, we can find those which will not introduce very serious errors. By "serious errors" I mean that if full scale deflection of the galvanometer is of the order of 2 inches, we would not permit galvanometer trace deflections of more than about .05 or .06 inch under severe shock--these deflections being measured with no electrical signal, or with a constant electrical signal applied to the galvanometers. The galvanometers which we purchase we usually select individually from a lot. The criterion for this selection is that the deflection of the galvanometer trace not exceed .01

inch per g, which is evaluated statically and not dynamically. The galvanometers do not perform as well as that under shock tests.

We do give very serious attention to the effect of shock on galvanometers. Some time ago a test was carried out by one of our contractors. The extraneous effects upon the galvanometers were about 75 percent of the peak readings which were obtained during the test. By isolating the galvanometers, these results were verified.

J. PAUSEY, R.N.S.S: We tried to use strain gages on the CAMERON, but we found considerable trouble with them in the field. Do you use them to a large extent in aircraft in flight, or do you have laboratory conditions for most of your tests? Do you have any tips in techniques?

C. G. WEEBER: Probably the best and only check on the strain gage itself is that great care must be exercised when the gage is applied to the structure, and I believe Mr. Weiss has conducted a series of tests in the laboratory where different bonding methods have been investigated. The following was the procedure of applying gages to the external structure of a seaplane, which is probably the most severe condition that you will encounter. In this case, the gages were cemented to the structure with Duco cement and allowed to dry for 24 hours. Then the gage area was coated heavily with Petrosene wax and 2-inch-wide strips of airplane fabric were wrapped around the structure and then heavily doped and allowed to dry. This was repeated two or three times. Also, a coating of Neoprene cement was put on the gages and subjected to heating and drying by infrared lamp. Finally, a metallic cover was placed around the structure. We use strain gages quite extensively in aircraft testing, and great care must be exercised in applying them; but they have been reliable. In this particular instance, where the airplane was subjected to rough water

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landings, the gages are still satisfactory after five months of testing.

D. E. WEISS: Such elaborate precautions are not always necessary. The case described by Mr. Weeber is a rather extreme one in which the gage was external to the seaplane--a rather difficult set of conditions. In ordinary flight tests, it is usually sufficient merely to cover the gage area with Petrosene "A" wax. Our tests usually extend over a rather long period of time. Our flight test programs are rarely completed in less than three months. We have every reason to believe that the gage is satisfactory,

as attested to by load calibrations of the structures before and after field tests.

F. F. VANE, DTMB: We have applied strain gages to ships, particularly below the water line on structural members and on shafts. There are two main difficulties. One is to be sure that the surface is clean and dry. We have used grinding wheels, etc. to get the surface flat and clean and have even used hair dryers to make sure the area was dry and not too cold. Then we used Duco cement. Gages installed in that fashion have stayed put for periods of months at a time.

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BRIEF RESUME OF
RECENT BRITISH SHOCK TRIALS IN SHIPS

By
J. E. Shaw, R.N.S.S.

This paper deals with the main results and conclusions from shock trials carried out recently on ships, including the broad characteristics of shock on items throughout the surface ship and the submarine. The maximum severities of shock recorded on the trials are tabulated, and the design requirements for shock resistance of machinery and equipment are discussed. The extent to which earlier theories have been justified and the gaps in present information on shock in ships are outlined.

INTRODUCTION

It is the aim of British designers of naval equipment to design their gear to withstand shock in ships up to the point of uncontrollable flooding in the section of the ship in which the gear is situated, either by making the equipment inherently strong enough to withstand the maximum shock forces and movements without damage or by mounting on flexible supports.

To further this end and to increase our basic knowledge on the nature and severity of shock in different classes of ship, up to the point of uncontrollable flooding, experiments are envisaged which will eventually cover the range of ships from submarine to battleship.

So far shock trials have been completed against the following ships.

- (1) The destroyers CAMERON and AMBUSCADE - the latter to extend our knowledge of shock severities in destroyers up to the point of uncontrollable flooding and to check the broad conclusions formulated in the CAMERON report.

- (2) The submarine PROTEUS when surfaced, and REPEAT JOB 9 (the section of an A class submarine) both on the surface and when submerged.

- (3) The cruiser EMERALD.

It has been our practice in shock in ships trials to install and record the movements of special castings or forgings designed to have great rigidity, in order to obtain the bodily movements of the mass unobscured by local vibrations on the portion of the items where the measuring instruments are situated.

The accelerations derived from such records multiplied by the mass should give forces exerted by the supports on the items and by the item on the supports.

These masses serve a threefold purpose:

- (1) To determine the bodily movement of objects;
- (2) To form a reference for comparing shock characteristics in different classes of ship;
- (3) To assist in calibrating shock testing machines.

In addition to records taken on masses, records have been taken of the movements of machinery items and guns.

DESTROYERS

As the CAMERON results influenced our instrumentation for later trials, it is probably opportune to reiterate some of the broad conclusions from the CAMERON trial before proceeding to discuss the later ones.

Figure 1 shows the shock characteristics on the hull framing and plating as recorded by piezoelectric accelerometers. High-frequency accelerations amounting to several thousand g can be seen on the records for the shell plating. Figure 2 shows the shock characteristics on a bulkhead immediately above the positions where the hull records were taken. It will be seen that the high-frequency accelerations are severely attenuated and do not exceed the medium-frequency accelerations. This was also found for items of machinery.

Figure 3 gives typical shock characteristics on the shell plating recorded by velocity meter, and Figures 4 and 5 typical characteristics of shock on a bulkhead, on a 1-ton casting representing a machinery item, and on an item of machinery.

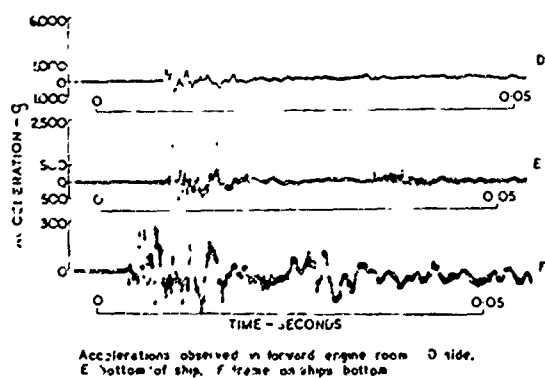


Fig. 1 Typical Accelerometer Records 300 Pounds Amatol Fired 200 Feet from Ship's Side, 50 Feet Deep.

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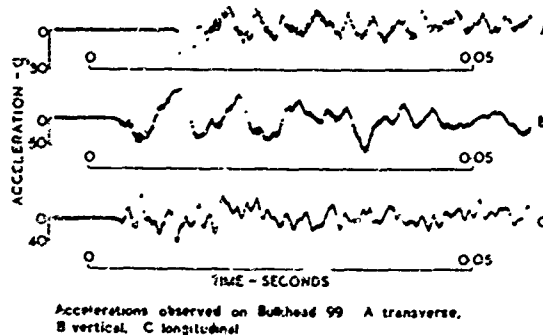


Fig. 2 Typical Accelerometer Records, 300 Pounds Amatol Fired 200 Feet from Ship's Side, 50 Feet Deep.

As no large high-frequency accelerations were recorded on CAMERON except on the hull structure, the evidence from these trials indicated that directly transmitted stress waves set up by underwater explosions were of insufficient intensity to cause failures except in very brittle materials. Failures were caused, in general either by relative motion between independent components leading to mechanisms failing, opening and closing of contacts, etc., or to relative motion between different parts of the same item, resulting in excessive strain at points where there were large bending moments and thus causing either permanent distortion of the parts where the material was ductile or fracture of parts when the material was brittle.

Thus velocity meters were chosen as our main instrument for recording the characteristics of shock, as we could obtain more readily from velocity time records information on the damaging characteristics of shock (i.e., accelerations associated with displacement, maximum velocities, etc.) than by using accelerometers.

In addition to the characteristics recorded by the velocity meter, items in the ship will be subjected to forces caused by the bodily movement of the ship as a whole and by the vertical oscillation

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of the ship as a free-free beam. Although the accelerations from this cause are low, the displacements are high (several inches) and such movements can result in failure to certain classes of apparatus (e.g., gyro-compass suspensions) unless mountings are designed to protect against these low-frequency (2-3 cps) high-displacement oscillations.

The second destroyer to be used for controlled shock trials from noncontact underwater explosions was AMBUSCADE. This ship was an A class destroyer built in 1928 and had a length of 322 feet, beam of 31 feet, and a displacement of 1700 tons in her trial condition (draught

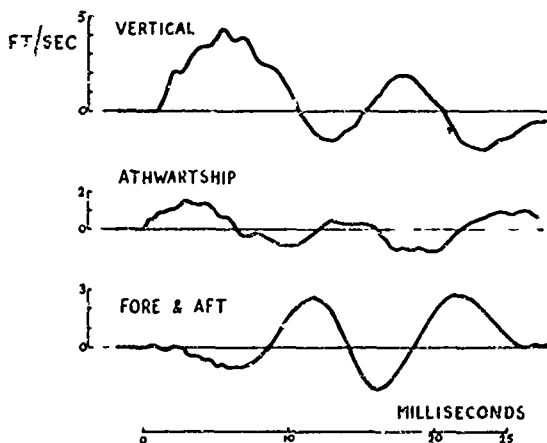


Fig. 4 Typical Velocity-Time Records on a Bulkhead in CAMERON. 1000 Pounds Amatol, 300 Feet Outb'd., 100 Feet Deep.

10 feet 8 inches forward, 10 feet 3 inches aft). Similar dimensions for CAMERON were length, 314 feet; beam, 31 feet; displacement, 1000 tons during trials (draught 8 feet 2 inches).

Both AMBUSCADE and CAMERON had framing 1 foot 9 inches apart, but the AMBUSCADE frames were somewhat stiffer than those on CAMERON, while the shell plating on CAMERON was, in general, thicker than on AMBUSCADE.

Two stations in AMBUSCADE were chosen to fire against, one just forward of the break of the fo'castle and one just abaft

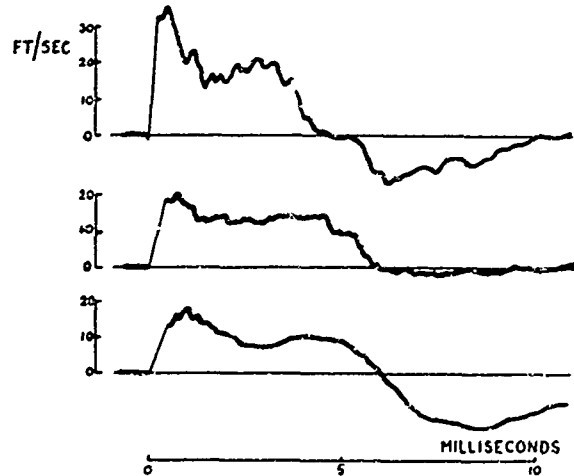


Fig. 3 Typical Velocity-Time Records on Shell Plating on CAMERON. 300 Pounds Amatol, 30 Feet Outb'd., 100 Feet Deep.

the after engine-room bulkhead, and instrument positions were arranged accordingly. In all, there were 49 instrument positions for recording the movements of masses on the hull, on bulkhead, on decks, and on machinery items and guns.

Figure 6 gives a general layout of some of the principal instrument positions in AMBUSCADE, the positions at which charges were fired, and the charge weights.

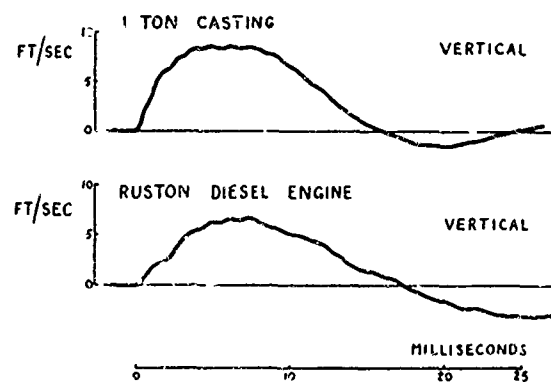


Fig. 5 Typical Velocity-Time Records on Machinery Items on Seatings Built Up from the Ship's Framing. 300 Pounds Amatol, 98 Feet Outb'd., 64 Feet Deep.

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In addition to the main shock tests, a number of minor shots (33 pounds Torpex) were detonated at a distance of 140 feet from the hull and at a depth of 130 feet in an attempt to increase our knowledge on the dynamic properties of mild steel, cast steel, D.W. steel, high tensile brass, and Admiralty gun metal at the rates of loading experienced due to shock in ships.

For this experiment, a mass of 900 pounds was secured to its seating by two similar specimens of the metal under observation, in lieu of holding-down bolts. A velocity meter was mounted on the mass, and it was hoped that the forces on the specimens could be determined from the decelerations of the mass. Figure 7 gives a sketch of the arrangements.

The shock forces were not purely vertical, and the horizontal component tended to distort the specimens and introduce additional friction, which to some extent complicated the results.

This experiment did, however, confirm the indications in the CAMERON report that under the rates and duration of loading caused by shock in ships, the yield points of mild steel, cast steel, and D.W. steel were considerably increased and that for stresses somewhat above the static U.T.S., little permanent set was recorded. For the high tensile brass and Admiralty gun metal, little increase in the yield point or U.T.S. was recorded.

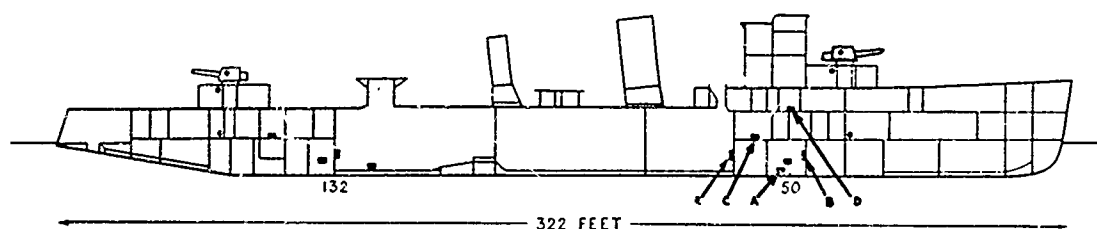
For design purposes, the permissible stresses for the materials could be increased as follows:

Mild steel from 16 to 20 tons psi
Cast steel from 16 to 18 tons psi
D.W. Steel from 18½ to 24 tons psi

Characteristics of Shock

The characteristics of shock on *AMBUSCADE*, recorded by electromagnetic velocity meters on masses on the ships

INSTRUMENT POSITIONS



CHARGE POSITIONS

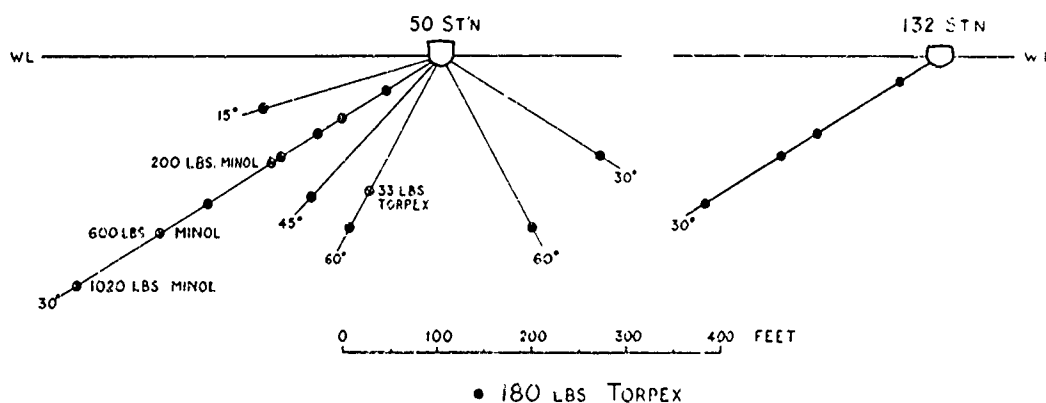


Fig. 6 HMS AMBUSCADE

framing or masses on bulkheads and on decks, are given in Figures 8 and 9 for shot A.3 (180 pounds Torpex detonated 137 feet from the ship's hull at an angle of 30°) 75 feet deep. $\sqrt{\frac{W}{D}} = 0.12$.

Figure 8 gives the vertical components. The maximum velocity for these components generally occurred at the first peak (as found in CAMERON), and this component generally decays without exhibiting any lower frequency components.

Figure 9 gives the vertical, athwartships and fore and aft components for No. 50 bulkhead and shows the relative severities of these components.

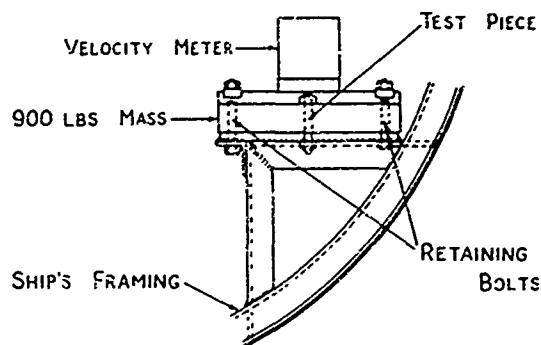
The maximum velocities for these horizontal components rarely occur at the first peak.

For comparison, some of the velocity-time traces obtained on the CAMERON trials are given in Figure 10 (depth of shot, 50 feet).

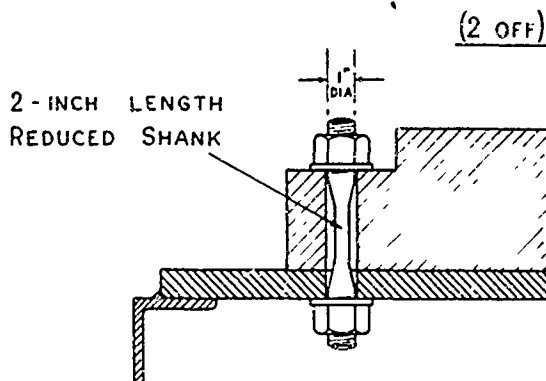
There are three main points of difference between the broad characteristics obtained on CAMERON and those obtained on AMBUSCADE:

(1) The time to maximum velocity of masses on the hull and on bulkheads in AMBUSCADE was much greater than that recorded in CAMERON. This can be explained to some extent by the shell plating on AMBUSCADE being thinner and more heavily loaded than on CAMERON.

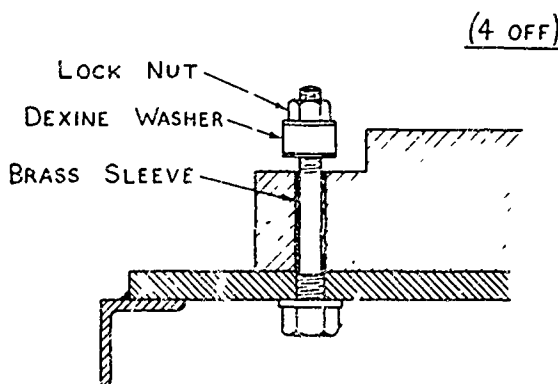
(2) The decelerations on masses representing machinery items on the hull were a higher percentage of the accelerations than on CAMERON and, in some cases, were actually greater than the accelerations. The decelerations, as shown in the CAMERON report are influenced to some extent by the stiffness of the ship's section rather than the stiffness of the shell plating; and, as the framing in AMBUSCADE was much stiffer than that on CAMERON, it is suggested that this is at least partly responsible for the change in the broad characteristics of shock.



A



B



C

Fig. 7 HMS AMBUSCADE. Dynamic Tests. (A, B) Details of Test Pieces, (C) Details of Retaining Bolts.

(3) The frequency of oscillation of masses on the decks of AMBUSCADE was somewhat higher than those recorded on CAMERON. This was due to the generally stiffer construction of the decks as a whole.

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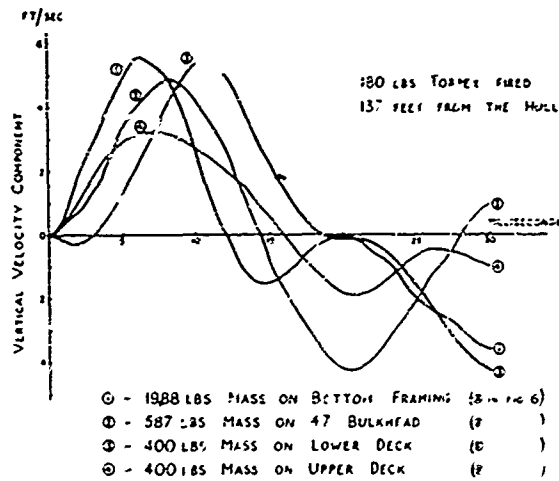


Fig. 8 HMS AMBUSCADE. Velocity-Time Characteristics.

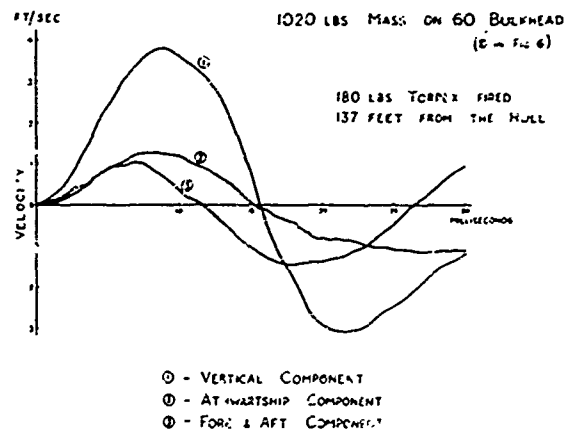


Fig. 9 HMS AMBUSCADE. Velocity-Time Characteristics.

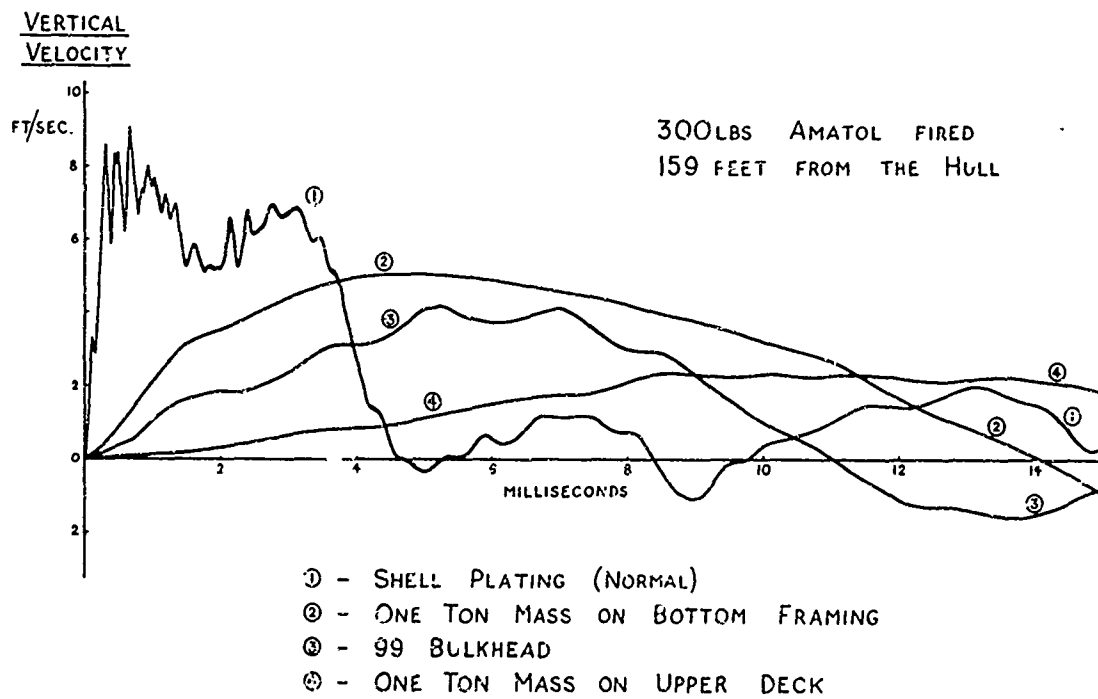


Fig. 10 HMS CAMERON. Velocity-Time Characteristics.

The characteristics of shock are of importance when considering flexible mountings for machinery or equipment. If machinery or equipment is attached to structures which give the assembly a low natural frequency, flexible mountings are unnecessary and, indeed, may even do harm unless carefully designed to prevent bottoming.

Shock Severity in Destroyers

As a result of the CAMERON trials, it was found that the most severe component of shock from noncontact underwater explosions was the vertical one, and that the vertical shock characteristics (maximum velocity, initial mean acceleration, and first peak of displacement) had a sensibly linear relationship with $\sqrt{\frac{W \sin \theta}{D}}$ where W = equivalent charge

weight of Amatol explosive in pounds and θ and D defined, as in Figure 11, up to the point where plastic deformation of the hull occurs. This sensibly linear relationship in the elastic range with $\sqrt{\frac{W \sin \theta}{D}}$ which we call the shock factor

was verified on AMBUSCADE, and typical plots are given in Figures 12 to 14, which show the relationship between this parameter and the maximum velocities, initial mean accelerations, and first peak of displacement for casting on the hull, on bulkheads, and on decks.

The approximate formulae developed in the CAMERON report for estimating the maximum values of velocity and acceleration for machinery items and items on bulkheads held to within 10 percent for items in AMBUSCADE, but it must be remembered that both these ships were built on the transverse framing system, and the more modern longitudinal system may appreciably affect the application of the CAMERON formulae.

The final shot against AMBUSCADE was a 180 pound Torpex Mk. XI depth charge detonated 36.5 feet from the ship's hull just abaft the engine room and at a depth of 25 feet. $\sqrt{\frac{W}{D}} = 0.45$

The maximum values of shock severity are given in Table I and compared with the maximum severities of shock in CAMERON.

The table indicates that the shock severity in AMBUSCADE, except on the decks, did not exceed that recorded on the CAMERON trial.

SUBMARINES

The nature and severity of shock in submarines due to noncontact underwater explosions was measured in shock trials against the submarine PROTEUS when surfaced and against REPEAT JOB 9 (the central portion of an A class submarine) both surfaced and submerged. It was not possible to carry out trials against PROTEUS when submerged, as there were no lifting craft available to raise this size of submarine should compartments flood after a shot. REPEAT JOB 9 gave a link between shock characteristics in surfaced and submerged conditions.

PROTEUS was a PARTHIAN class submarine laid down in 1927 and had the following dimensions:

Standard displacement	-	1475 tons
Surface displacement	-	1767 tons
Submerged displacement	-	2040 tons
Displacement during shock trials	-	1886 tons
Length (extreme)	-	289 ft. 2 in.
Breadth (extreme)	-	29 ft. 10 in.
Pressure hull plating	-	35 lbs. psf
Frame spacing	-	1 ft. 9 in.

No. 2 and No. 3 battery groups were removed from the submarine prior to the shock trials, in addition to the 4-inch gun, gun platform and mounting; all ammunition; store, anchors, and cable anchor; propellers; linings and loose fittings; and 10 tons of ballast stored in No. 2 battery tank. In this way it is possible, with all tanks full, to have the submarine in its "trimmed down" condition for trials

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As a result of the CAMERON trials, it was found that the most severe component of shock from noncontact underwater explosions was the vertical one, and that the vertical shock characteristics (maximum velocity, initial mean acceleration, and first peak of displacement) had a sensibly linear relationship with $\sqrt{\frac{W \sin \theta}{D}}$ where W = equivalent charge

weight of Amatol explosive in pounds and θ and D defined, as in Figure 11, up to the point where plastic deformation of the hull occurs. This sensibly linear relationship in the elastic range with $\sqrt{\frac{W \sin \theta}{D}}$ which we call the shock factor

was verified on AMBUSCADE, and typical plots are given in Figures 12 to 14, which show the relationship between this parameter and the maximum velocities, initial mean accelerations, and first peak of displacement for casting on the hull, on bulkheads, and on decks.

The approximate formulae developed in the CAMERON report for estimating the maximum values of velocity and acceleration for machinery items and items on bulkheads held to within 10 percent for items in AMBUSCADE, but it must be remembered that both these ships were built on the transverse framing system, and the more modern longitudinal system may appreciably affect the application of the CAMERON formulae.

The final shot against AMBUSCADE was a 180 pound Torpex Mk. XI depth charge detonated 36.5 feet from the ship's hull just abaft the engine room and at a depth of 25 feet. $\sqrt{\frac{W}{D}} = 0.45$

The maximum values of shock severity are given in Table I and compared with the maximum severities of shock in CAMERON.

The table indicates that the shock severity in AMBUSCADE, except on the decks, did not exceed that recorded on the CAMERON trial.

SUBMARINES

The nature and severity of shock in submarines due to noncontact underwater explosions was measured in shock trials against the submarine PROTEUS when surfaced and against REPEAT JOB 9 (the central portion of an A class submarine) both surfaced and submerged. It was not possible to carry out trials against PROTEUS when submerged, as there were no lifting craft available to raise this size of submarine should compartments flood after a shot. REPEAT JOB 9 gave a link between shock characteristics in surfaced and submerged conditions.

PROTEUS was a PARTHIAN class submarine laid down in 1927 and had the following dimensions:

Standard displacement	-	1475 tons
Surface displacement	-	1767 tons
Submerged displacement	-	2040 tons
Displacement during shock trials	-	1886 tons
Length (extreme)	-	289 ft. 2 in.
Breadth (extreme)	-	29 ft. 10 in.
Pressure hull plating	-	35 lbs. psf
Frame spacing	-	1 ft. 9 in.

No. 2 and No. 3 battery groups were removed from the submarine prior to the shock trials, in addition to the 4-inch gun, gun platform and mounting; all ammunition; store, anchors, and cable anchor; propellers; linings and loose fittings; and 10 tons of ballast stored in No. 2 battery tank. In this way it is possible, with all tanks full, to have the submarine in its "trimmed down" condition for trials

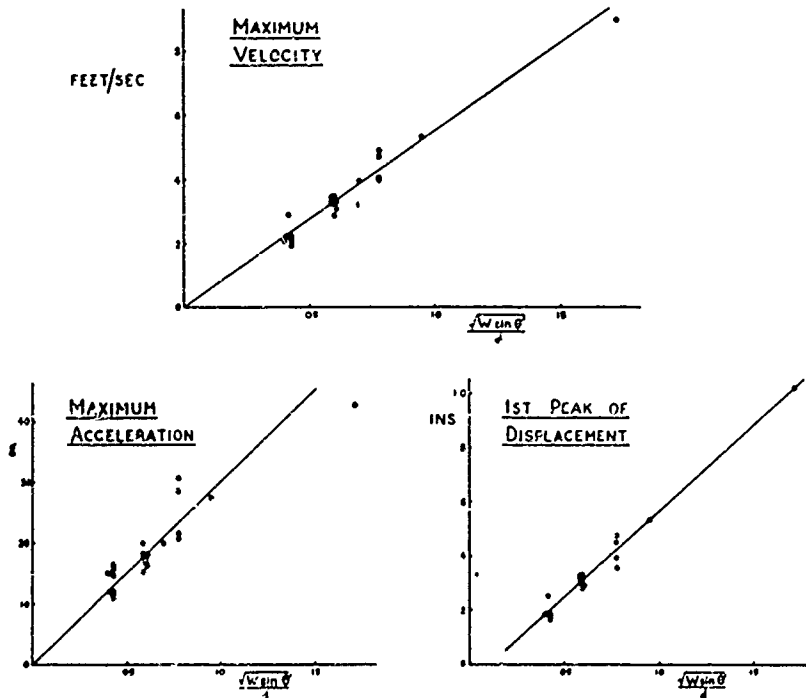


Fig. 13 HMS AMBUSCADE. Plots for Vertical Components of Shock. 527 Pounds Mass on Bulkhead (B in Fig. 6).

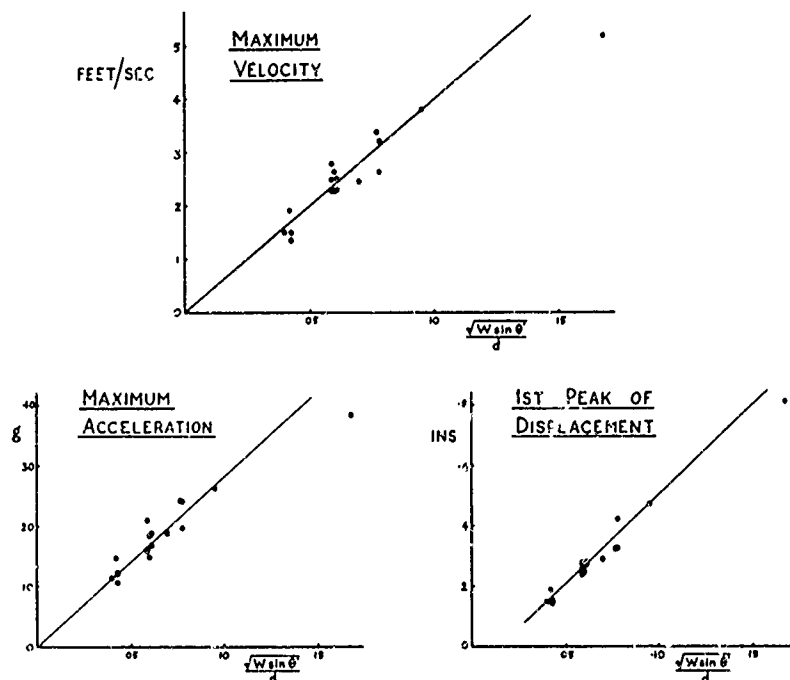


Fig. 14 HMS AMBUSCADE. Plots for Vertical Component of Shock. 400 Pounds on Upper Deck (D in Fig. 6).

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TABLE I
COMPARISON OF MAXIMUM SHOCK SEVERITIES

ITEM	CAMERON								AMBUSCADE							
	MAXIMUM VELOCITY FT/SEC			MAXIMUM ACCELERATION g			MAX DECEL g	1ST PEAK DISPL. INS.	MAXIMUM VELOCITY FT/SEC			MAXIMUM ACCELERATION g			MAX. DECEL g	1ST PEAK DISPL. INS.
	V	A	F&A	V	A	F&A	V	V	V	A	F&A	V	A	F&A	V	V
ONE TON MASS ON BOTTOM	13	5.5	1.5	170	28	20	70	1.6	14	4	-	110	40	-	120	1.5
MACHINERY ON BOTTOM	22	2	-	220	24	-	110	2.3	16	4	-	180	40/50	-	90/100	-
MASS ON LOWER DECK	8	-	-	25	-	-	-	1.3	14	-	-	60	-	-	60	1.3
MASS ON UPPER DECK	16	-	-	40	-	-	-	2.3	7	-	-	45	-	-	40	1.0
MASSES ON BULKHEADS	13.5	3	3	130	20	15	-	1.3	11	4	3	50	20	20	70	1.4
SINGLE 4.7 INCH GUN									7			25			18	1.6

V - VERTICAL

A - ATHWARTSHIP

F & A - FORE & AFT

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(draught 16 feet 10 inches) and to have a reserve of buoyancy by blowing the tanks. Arrangements were made so that Nos. 4 and 5 main ballast tanks could be blown (by H.P. air) from the bridge in order to recover reserve buoyancy before entering the submarine.

No. 90 bulkhead was chosen as the main station to fire against, with a few shots against stations 130 and 137.

A 1-ton casting was installed at station 92/93 on the starboard side and a ½-ton casting secured overhead at station 86/87. Both were fitted with velocity meters for recording the vertical and athwartship components of the shock motion.

Instruments were fitted to the pressure hull plating and framing, the main engine, main motor, switchboard, to various items of auxiliary machinery, and to mild steel dummy cells in a small battery tank. The general layout of instruments and the charge positions in the plane of 90 bulkhead are shown in Figure 15. Relative displacement indicators, resonance meters

and copper crusher units were liberally used to back up the readings of the velocity meters.

The first series of explosions, using the hedgehog (33-pound Torpex) charge, were made to determine the angle at which the optimum shock effects occurred on equipment in a surfaced submarine as a result of dropping depth charges at a given horizontal distance from the vessel.

The remaining and more severe shots, which included charges of 315-pound Torpex 330-pound Minol, 435-pound Minol, and 2000-pound Amatol, were chosen to determine the vulnerability of the various items of equipment and the effect of varying the weight and composition of the charge.

Characteristics of Shock

The characteristics of shock recorded on the pressure hull plating and framing and on the various machinery items and casting are given in Figures 15 to 19.

Figure 16 gives the velocity-time signature for shell plating and framing

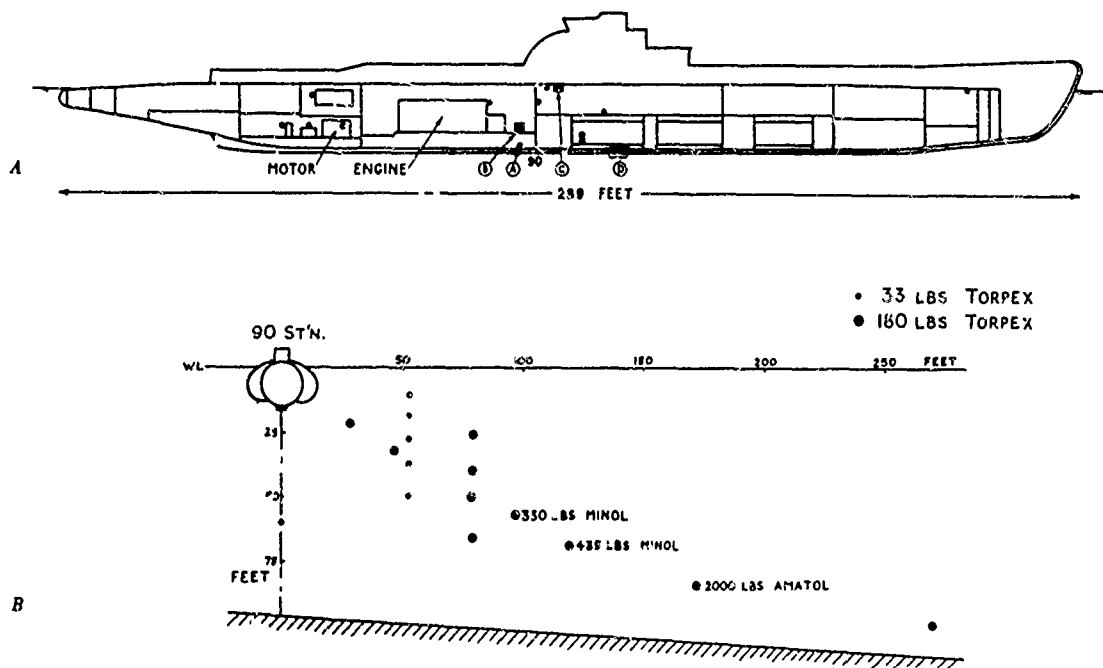


Fig. 15 HMS/M PROTEUS. (A) Instrument Positions; (B) Charge Positions.

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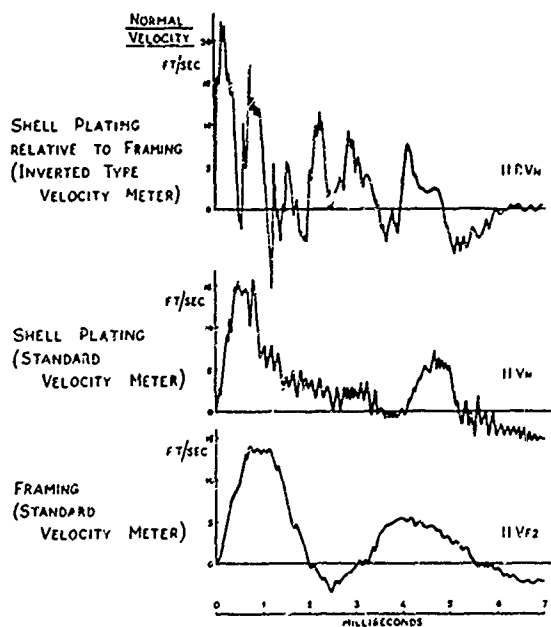
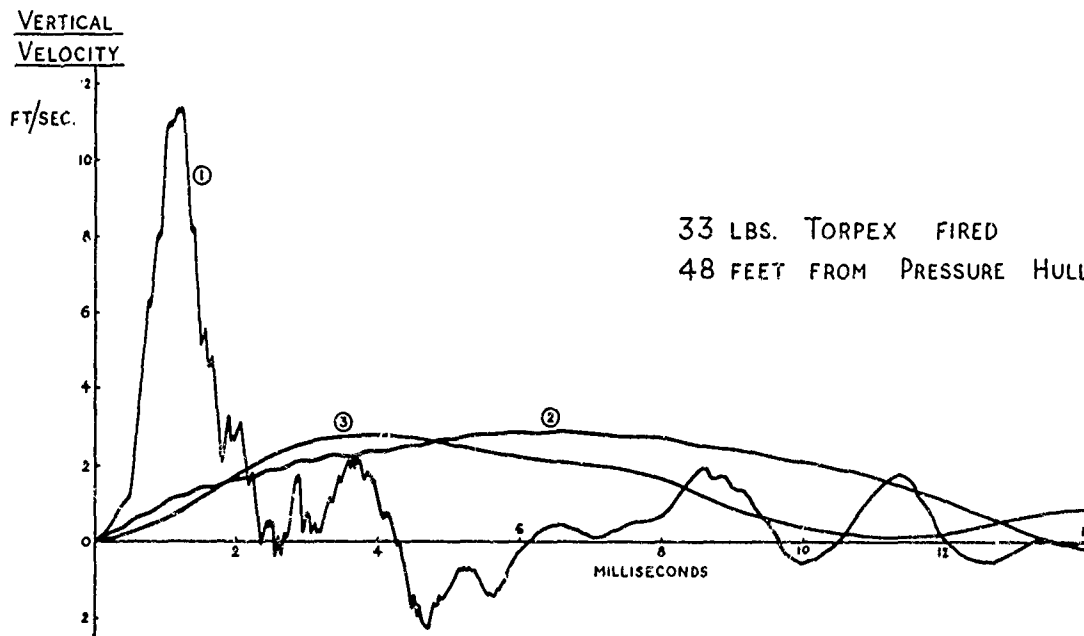


Fig. 16 HMS/M PROTEUS. Velocity-Time Characteristics (D in Fig. 15). 33 Pounds Torpex Fired 48 Feet from Pressure Hull.

at stations 73-75 in No. 3 battery tank from a 33-pound Torpex charge detonated 48 feet from the pressure hull at station 90 and at a depth of 28 feet.

The signature $11V_{F2}$ gives the record on Frame 74, $11V_N$ gives the signature of the pressure hull plating between Frames 74 and 75, and $11RV_N$ gives the relative velocity between plating and framing at stations 73-74. The relative velocity meter had only the weight of the coil assembly secured to the plating (the weight of the magnet system, etc., being borne by the two adjacent frames) and, in consequence, the velocity recorded on the plating was very much higher than that recorded by the standard velocity meter, which weighs approximately 35 pounds.

Figure 17 shows the shock signature on the shell plating below the 1-ton casting at station 92/93 and the vertical components of the shock characteristics on this casting and on the $\frac{1}{2}$ -ton casting overhead at station 86/87, all recorded by the standard type of velocity meter.



33 LBS. TORPEX FIRED
48 FEET FROM PRESSURE HULL

Fig. 17 HMS/M PROTEUS. Velocity-Time Characteristics. (1) Shell Plating Normal (A in Fig. 15); (2) 1-Ton Mass on Tank Top (B in Fig. 15); (3) $\frac{1}{2}$ -Ton Mass on Framing Overhead (C in Fig. 15).

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It will be seen that the maximum velocity on this pressure hull plating, although slightly nearer the explosion, was less than that recorded on the pressure hull plating in No. 3 battery tank. The heavy thickness of plating made this possible in conjunction with the increased loading on the frames in this part of the submarine (engine room).

The shock signature on the two castings showed no pronounced high-frequency oscillation, and the athwartship components (Figure 18) were very much lower than the vertical ones.

Figure 19 shows the shock signature for the main motor and main engine shot vertically below keel 59 feet deep.

The main engine records indicate that the position chosen for the velocity meters was not ideal, as local vibrations appear to mask the record of the main bodily movement of the machine.

In addition to these characteristics, there is the low-frequency oscillation caused by whipping. No reliable whipping records were obtained on this trial but it is hoped in future experiments to record the whipping of submarines caused by noncontact underwater explosions.

Shock Severity

It was found that with the submarine surfaced and charges dropped at a given horizontal distance from the axis of the submarine, the greatest shock effect is produced if the charge explodes on a plane making an angle of 27° - 30° with the horizontal at the axis of the submarine.

The values of maximum velocity and initial mean acceleration recorded on items of machinery and equipment for a given value of shock factor were considerably lower than those recorded on destroyers, but the submarine, with its stiffer and thicker pressure hull, can withstand a very much

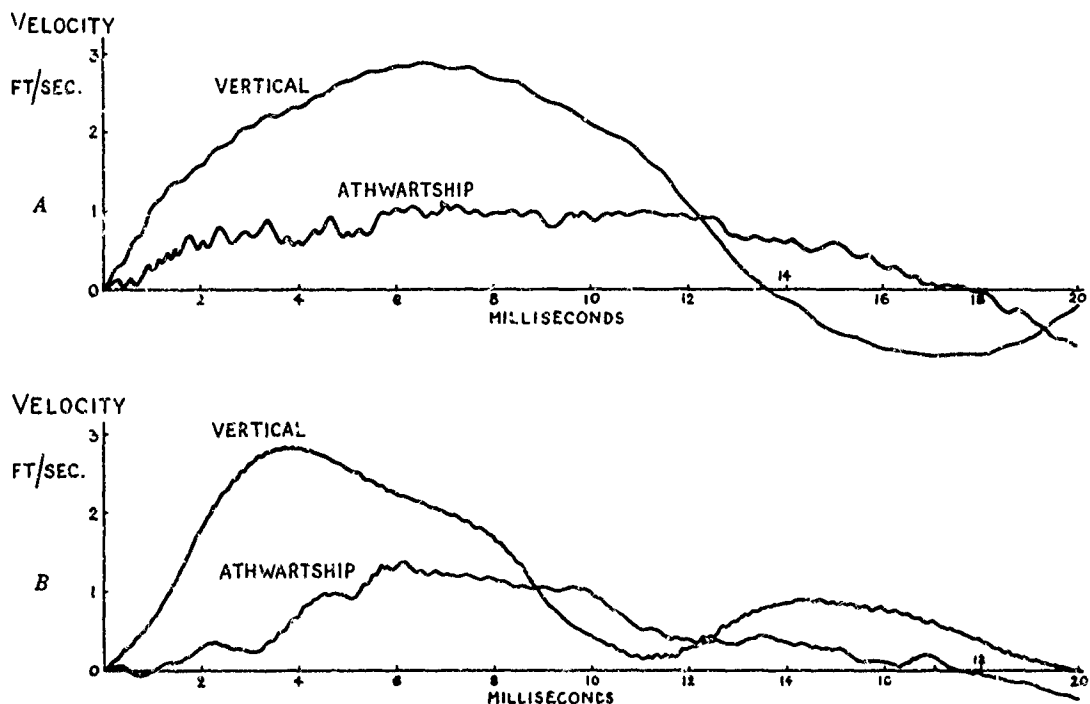


Fig. 18 HMS/M PROTEUS. Velocity-Time Characteristics. 33 Pounds Torpex Fired 48 Feet from Pressure Hull. (A) 1-Ton Mass on Tank Top (B in Fig. 15); (B) 1/2-Ton Mass on Framing Overhead (C in Fig. 15).

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higher value of shock factor before hull failure results. Thus, there is little difference in the maximum values of shock severity for machinery in destroyers and in submarines at shock factors corresponding to hull rupture in each case.

The final shot against PROTEUS, which caused severe damage in the externals and minor leaks in the pressure hull, was a 330-pound Torpex charge detonated 23-25 feet from the pressure hull and at a depth of 21.5 feet. ($\sqrt{\frac{W}{D}} = 0.7$).

The maximum values of shock severity estimated from the relationship between shock factor and shock severity which would have resulted had this shot been fired ahead of the various items in the submarine are given in Table II.

Most of the machinery and equipment in PROTEUS was of obsolete pattern, and minor failures occurred as the trial progressed. Securing arrangements of most items were inadequate and required strengthening. Strong recommendations to this effect were presented at the trial.

This trial was of the necessary background before commencing the REPEAT JOB 9 trial. It gave the necessary link between a hull failure and the submarine target.

REPEAT JOB 9

REPEAT JOB 9 was a specially-built submarine target vessel corresponding approximately to the central portion of an A class submarine complete with externals and compensating tanks and fitted with salvage ends.

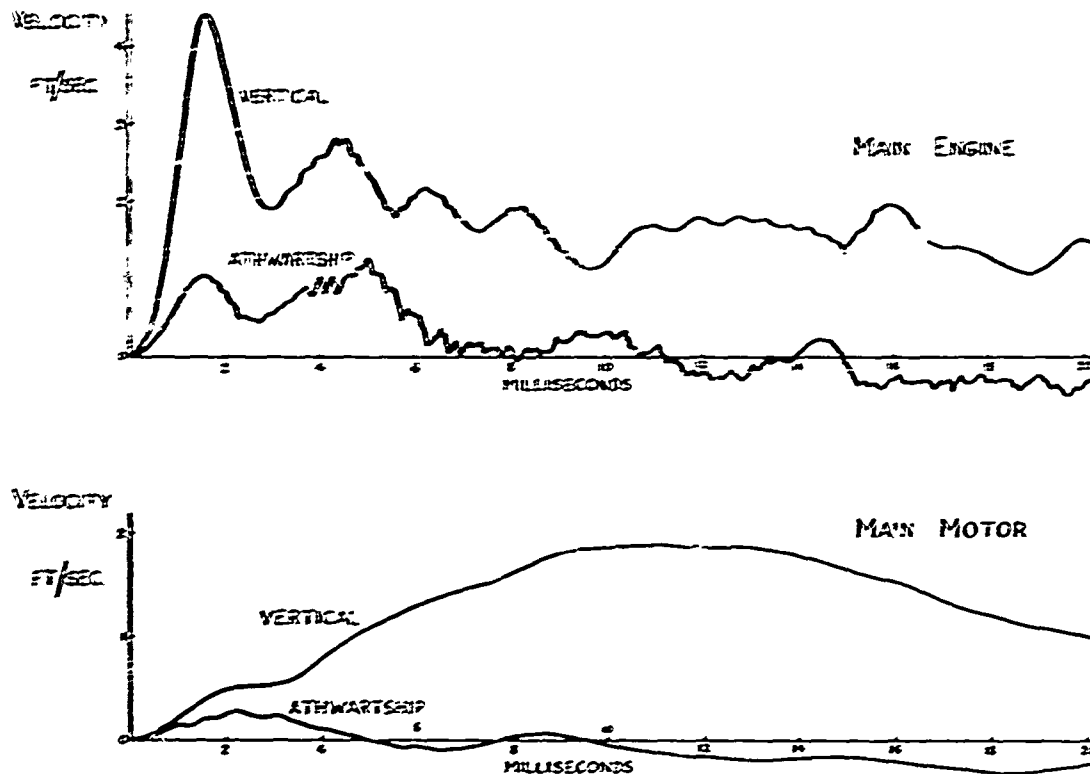


Fig 19 PROTEUS. Velocity-Time Characteristics. 33 Pound Torpex Fired 43 Feet from Pressure Hull.

It will be seen that the maximum velocity on this pressure hull plating, although slightly nearer the explosion, was less than that recorded on the pressure hull plating in No. 3 battery tank. The thickness of plating made this possible in conjunction with the increased loading on the frames in this part of the submarine (engine room).

The shock signature on the two castings showed no pronounced high-frequency oscillation, and the athwartship components were less than the vertical ones.

Figure 19 shows the shock signature for the main motor and main engine shot vertically below keel 59 feet deep.

The main engine records indicate that the position chosen for the velocity meters was not ideal, as local vibrations appear to mask the record of the main bodily movement of the machine.

In addition to these characteristics, there is the low-frequency oscillation caused by whipping. No reliable whipping records were obtained on this trial; but it is hoped in future experiments to record the whipping of submarines caused by noncontact underwater explosions.

Shock Severity

It was found that with the submarine surfaced and charges dropped at a given horizontal distance from the axis of the submarine, the greatest shock effect is produced by the large explosion on a plane making an angle of 45 degrees with the horizontal at the axis of the submarine.

The values of maximum velocity and initial mean acceleration recorded on items of machinery and equipment for a given value of shock factor were considerably lower than those recorded on destroyers, but the submarine, with its stiffer and thicker pressure hull, can withstand a very much

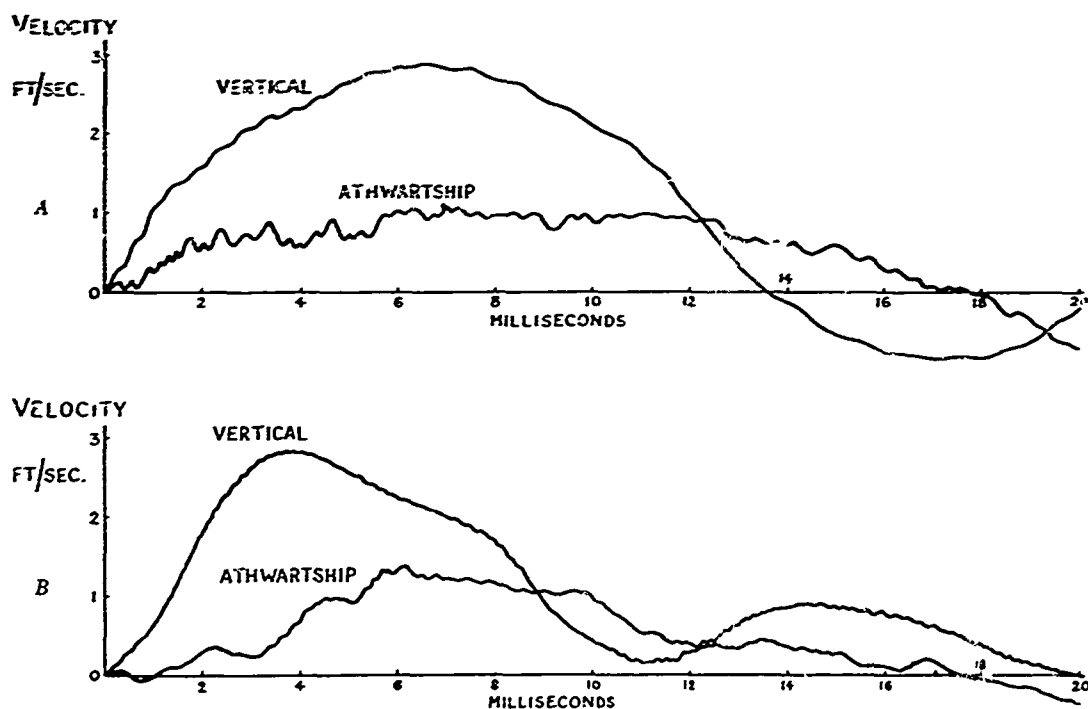


Fig. 18 HMS/M PROTEUS. Velocity-Time Characteristics. 33 Pounds Torpex Fired 48 Feet from Pressure Hull. (A) 1-Ton Mass on Tank Top (B in Fig. 15); (B) 1/4-Ton Mass on Framing Overhead (C in Fig. 15)

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higher value of shock factor before hull failure results. Thus, there is little difference in the maximum values of shock severity for machinery in destroyers and in submarines at shock factors corresponding to hull rupture in each case.

The final shot against PROTEUS, which caused severe damage in the externals and minor leaks in the pressure hull, was a 125-pound Torpex charge detonated 23-25 feet from the pressure hull and at a depth of 21.5 feet. ($\sqrt{\frac{W}{D}} = 0.7$).

The maximum values of shock severity estimated from the relationship between shock factor and shock severity which would have resulted had this shot been fired abreast the various items in the submarine are given in Table II.

Most of the machinery on PROTEUS was of obsolete pattern. The minor failures occurred as the trial progressed. Securing arrangements of valves were inadequate and required strapping. Strong recommendations to this effect were promulgated after the trial.

This trial gave us the necessary background before commencing the REPEAT JOB 9 trial, as it gave the necessary link between a fully loaded submarine and the submarine target.

REPEAT JOB 9

REPEAT JOB 9 was a training exercise in which the submarine target vessel corresponding approximately to the central portion of an A-1 submarine complete with externals and compensating tanks and fitted with salvage ends.

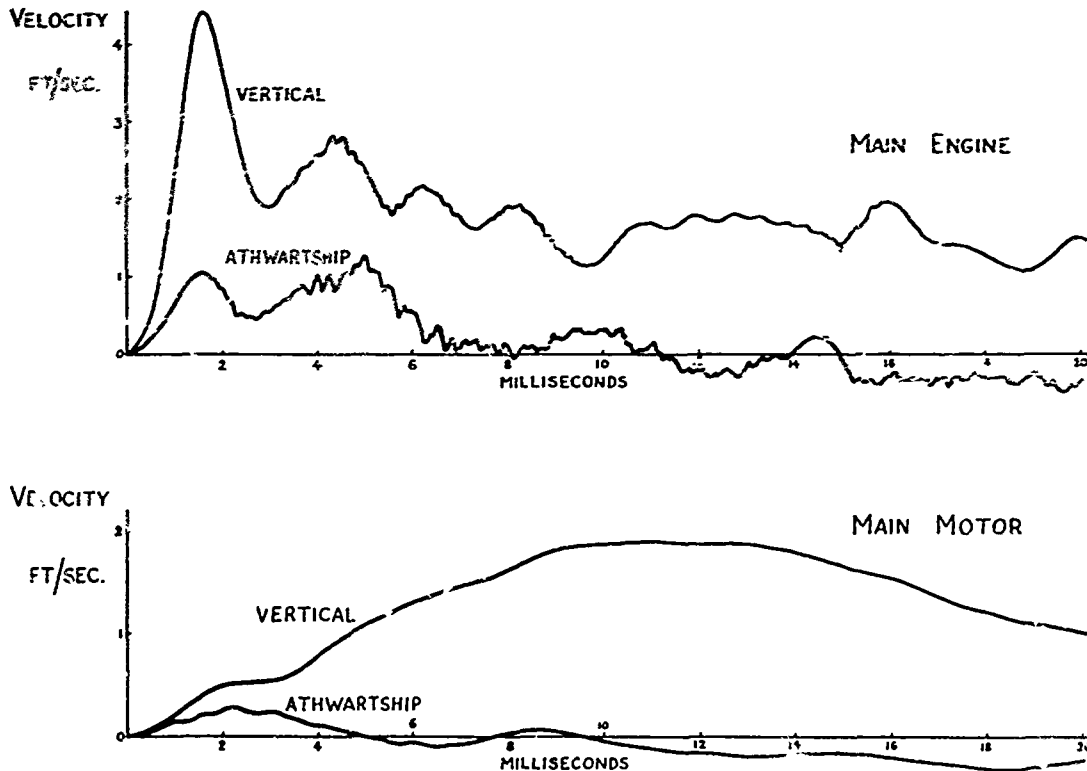


Fig. 19 HMS/M PROTEUS. Velocity-Time Characteristics. 33 Pounds Torpex Fired 43 Feet from Pressure Hull.

TABLE II
H.M.S./N. PROTEUS

ITEM	VERTICAL*			ATHWARTSHIP*		
	MAXIMUM VELOCITY FT/SEC	MAXIMUM ACCELERATION G	EST. PEAK DISPLACEMENT INCHES	MAXIMUM VELOCITY FT/SEC	MAXIMUM ACCELERATION G	EST. PEAK DISPLACEMENT INCHES
PRESSURE HULL PLATING*	75	7500	2.0	-	-	-
PRESSURE HULL FRAMING*	75	4200	1.4	-	-	-
ONE TON MASS	15.4	173	1.7	5.0	40	0.7
HALF TON MASS OVERHEAD	12.5	120	1.5	5.3	60	0.5
MAIN ENGINE	10.5	100?	1.6	5.1	-	-
MAIN MOTOR	12.2	30	1.9	3.8	50	0.3
BATTERIES (FLEXIBLY MOUNTED)	8.8	12	-	2.1	9	-

* PLATING & FRAMING RECORDS TAKEN NORMAL TO HULL

The dimensions of REPEAT JOB 9 were as follows:

Overall length	81 ft. 8 in.
External diameter of pressure hull	15 ft.
Pressure hull plating	31½ lb. psi (S. Quality)
Breadth over external tanks	20 ft. 8 in.
Displacement for surface shots (draught 16 ft. 6 in.)	498 tons
Displacement for submerged shots	545 tons
Negative buoyancy for submerged shots	4 tons (approx.)
Dead weight when full of water.	180 tons (approx.)

The following items were fitted in the main compartment:

- (1) Two battery tanks, each containing 36 A class submarine cells and 4 mild steel dummy cells (of the same weight and size as A class submarine cells) fitted with velocity meters. Both tanks were "stepped" and had rubber pads in the battery tank woodwork.
- (2) One ballast pump (50 tons/hr. at 100 feet head) on 16 - ARL flexible mountings Type 250 (B).
One trimming pump (12 tons/hr. at 124 feet head) on 8 - ARL flexible mountings Type 250 (S).
- (3) Three 1-ton special castings
Three ½-ton special castings both representing auxiliary machinery

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- (4) Miscellaneous items including depth gauges, standard valve, Z.P. air system, air bottles, etc.

The general arrangement plans and sections are shown in Figure 20.

150-pound Torpedex charges were used for this trial, and Figure 21 gives the positions at which charges were detonated.

Characteristics of Shock

The characteristics of shock on masses and on a dummy cell for similar shots when surfaced and submerged are given in Figures 22 to 26.

It will be seen that the shock signatures for items in the submarine, whether rigidly mounted or flexibly mounted, differ considerably for similar shots, depending on whether the submarine is surfaced or submerged.

For rigidly mounted items, (i.e., items reaching their maximum velocity in less than 3 milliseconds) the effect of submergence was to increase the decelerations by approximately 60 percent without any appreciable change to the values of maximum velocity or initial mean acceleration.

The flexibly mounted items (i.e., items reaching their maximum velocity in more than 10 milliseconds) the values of both the maximum velocity and initial mean accelerations, recorded with REPEAT JOB 9 surfaced, were reduced by about 50 percent for similar shots when submerged.

It will be seen that in most cases this is a definite divergence between the velocity-time traces for surfaced and submerged conditions commencing at between 2.5 and 4 milliseconds.

A tentative explanation would appear to be that these effects are partly due to diffraction of the pressure pulse around the hull and partly due to the increased resistance to motion of the hull when submerged.

Thus, on submergence, if it be assumed that the pressure pulse, after reaching points on the hull where the line to the charge position is tangential to the

pressure hull, can be diffracted around the hull at the velocity of sound in water, then as the diffracted pulse reaches points above the centre line of the submarine, the general effect will be to reverse the upward motion imparted by those below the centre.

This assumes that, with the hull submerged, a pressure acting radially inwards builds up around the hull, but since it is a result of diffraction, its values cannot be directly assessed.

Any effects of the pressure pulse near the sea surface will be largely nullified by sea surface cutoff, and thus one would not anticipate any appreciable reversal of force from the diffracted pressure pulse when the submarine is surfaced.

For explosions 70 feet from the nearest point on the hull of REPEAT JOB 9, this effect should be noticeable some 3 - 4 milliseconds after the first impingement of the pressure pulse on the hull. Also, the reaction effect of the increased resistance to motion should begin to influence items after the interval taken for stress waves to travel 180° around the hull and back (in this case about 2.8 milliseconds).

Thus, a divergence of the traces between 3 and 4 milliseconds for surfaced and submerged conditions could be explained by either hypothesis.

Rigidly mounted items which reach their maximum velocity in less than 3 milliseconds would have only their decelerations affected by this feature, while flexibly mounted items which had not reached their maximum velocity or accelerations in 3 milliseconds would have both these quantities reduced.

Shock Severity

It was found that over the larger range of angle explored in REPEAT JOB 9, shock severities gave a more linear relationship with $\frac{\sqrt{W}}{D} \sin \theta$ than with

$\frac{\sqrt{W \sin \theta}}{D}$. This can be partly explained

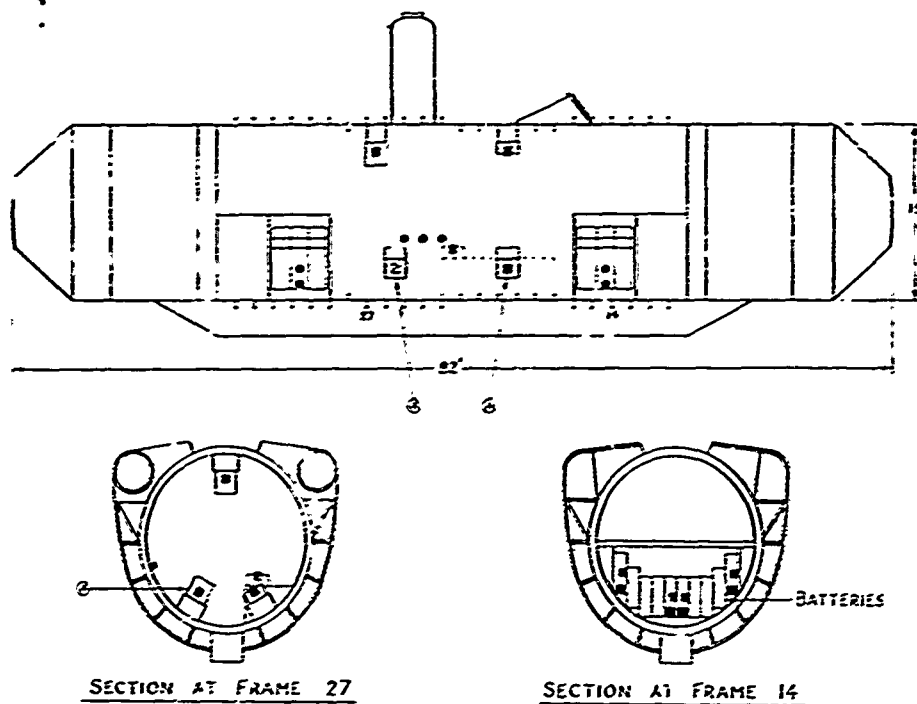


Fig. 20 REPEAT JOB 9. Instrument Position..

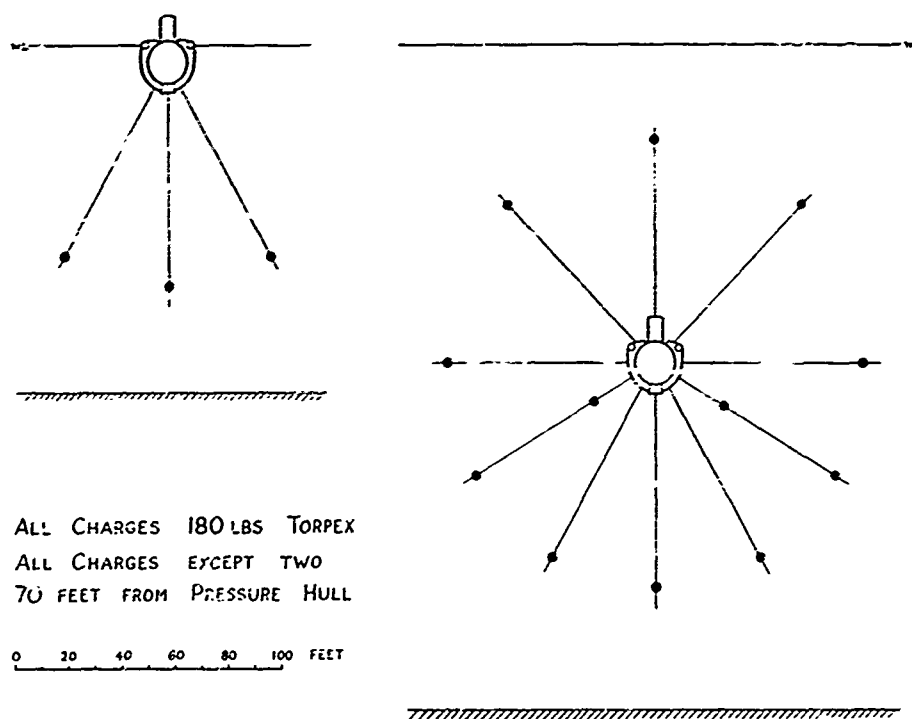
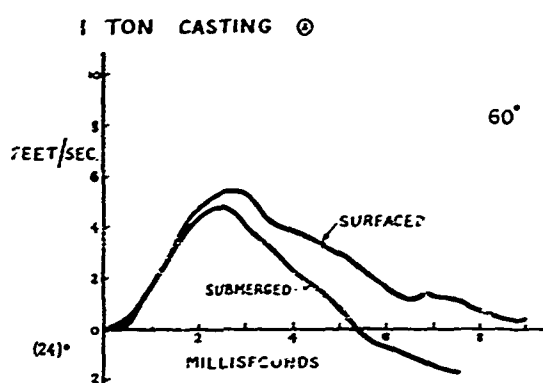
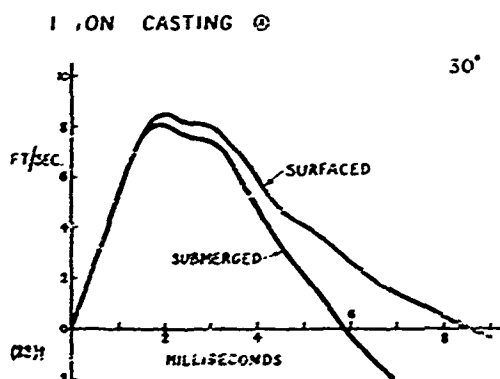
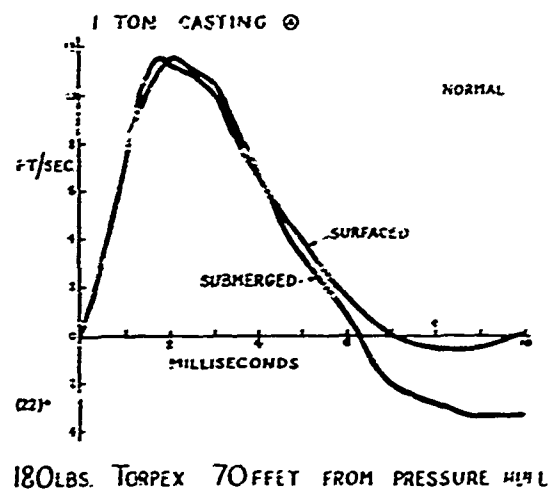
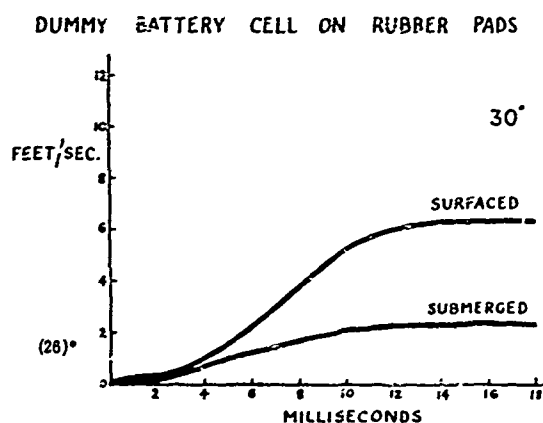
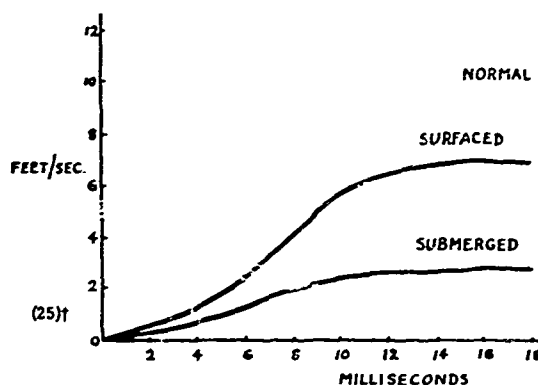


Fig. 21 REPEAT JOB 9. Charge Positions

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DUMMY BATTERY CELL ON RUBBER PADS



180 LBS TORPEX 70 FEET BELOW PRESSURE HULL

* 80 Pounds Torpex 70 Feet From Pressure Hull.

† 80 Pounds Torpex 70 Feet Below Pressure Hull.

Fig. 22 . 26 Velocity-Time Records from JOB 9 Showing Effect of Submerging.

by the very stiff cylindrical hull of the submarine, tending to cause the hull to move like a solid cylinder; whereas for a less stiff construction, the motion of the item is chiefly governed by the movements of plating surrounding its supports.

The penultimate shot (180-pound Torpex) was detonated at a distance of 24 feet ($\sqrt{\frac{W}{D}} = 0.75$) from the pressure hull with REPEAT JOB 9 submerged to a depth of 110 feet. This shot caused some slight plastic dishing of the pressure hull, and the maximum indentation was 1 1/4 inches. All machinery and the submarine cells were undamaged (with the exception of one corner cell which was cracked due to distortion of the battery tank sides) and machinery ran satisfactorily after the shot.

The final shot (180-pound Torpex) at 19 feet ($\sqrt{\frac{W}{D}} = 0.86$) from the pressure

hull caused two large tears in the pressure hull, one at station 21-22 and one at station 19, and between these the hull plating and framing had been pushed in to a maximum of 4 feet 6 inches taking the ballast pump platform inboard where it assumed a position at approximately 35° to the horizontal.

It would thus appear that submarine machinery mounted on noise absorbing mountings and submarine batteries in the rubber padded tanks, as in normal British practice, will withstand shock up to the point of lethal severity without damage. This is a considerable achievement.

The maximum values of shock severity recorded on items in REPEAT JOB 9 were:

		Velo- city	Accel- eration
Castings - 1/2 ton (normal)		29 fps	700 g
	1/2 ton (vertical)	18.5 "	320 g
	1/2 ton (athwartship)	12 "	220 g
Batteries (flexibly mounted)			
	vertical	6 "	64 g
	athwartship	6.7 "	73 g

Had the final shot been fired on the opposite side of the target, it is estimated that the 1-ton masses would have experienced maximum velocities of about 22 fps and initial mean acceleration of 500 g.

REPEAT JOB 9 was a very lightly loaded target compared with a completed submarine, and the shock severities are very much higher than those obtained on PROTEUS. (In addition, it should be added that REPEAT JOB 9 had a wholly welded structure, where PROTEUS had a riveted hull.) For example, if a shot of this severity (180-pound Torpex 19 feet from pressure hull) were being fired against PROTEUS, the estimated values of maximum velocity and initial mean acceleration (obtained by extrapolation) would be:

	Maximum Velocity	Initial Mean Acceleration
1-ton casting	18 fps	200 g
Main motors	13.8 "	90 g
Main engines	11.8 "	110 g (excluding the H.F. oscillations on record).

Further trials are being planned against ACE on A class submarines, with the object of verifying the maximum values of shock severity in submarines, to act as a proving trial for A class submarine equipment and, by means of an array of P.E. gauges around the outside of the pressure hull and velocity meters inside, to explore more fully the mechanics of the changes in shock characteristics when submerged.

CRUISERS

Shock trials were carried out against the cruiser EMERALD to determine the nature and severity of shock in double-bottom ships of the cruiser type.

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BERALD was an E class cruiser built in 1926, and had the following dimensions:

Length	570 ft.
Extreme Breadth	54 ft. 6 in.
Displacement	
during Trials	9510 tons
Outer bottom	
plating in way	
of shots	40 psi
Draught during	
trials	21 ft. 3 in.
	(aft.)
	18 ft. 10 in.
	(forward).

The frame spacing was, in general, 4 feet, except in the way of certain bulkheads where it was 2 feet, and near the stern where it was less than 2 feet.

Records were obtained of the shock characteristics on masses representing auxiliary machinery and equipment and on actual machinery items.

Figure 27 gives the general layout of the instrument positions and Figure 28 gives the positions at which charges were detonated.

Characteristics of Shock and Shock Severity

The broad characteristics of shock measured on masses in the double bottom, on the inner bottom, on bulkheads, and on decks is shown in Figures 19 to 31 (Shots 113 feet deep.) These figures show the general trend of attenuation of the medium-frequency characteristics at a section of the cruiser.

For a given shock factor, the vertical component of the shock characteristics on masses representing machinery was considerably lower than that recorded on destroyers, but the sternship component was somewhat larger.

The final shot against BERALD was a 1130-pound Cooper charge detonated 50 feet from the ship's hull at a depth of 41 feet.

Table III gives the maximum values of shock severity obtained on the BERALD trials.

Trials are proceeding to determine no-damage curves for various charge weights detonated against each class of ship. These curves will enable an estimate to be

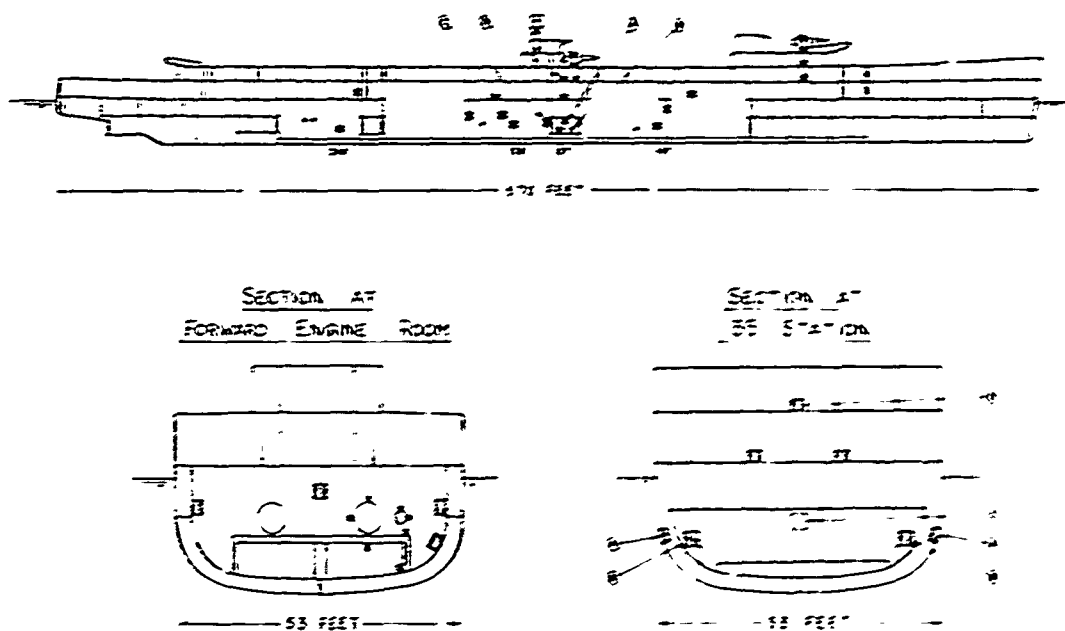


Fig. 27 HMS EBERALD. Instrument Positions.

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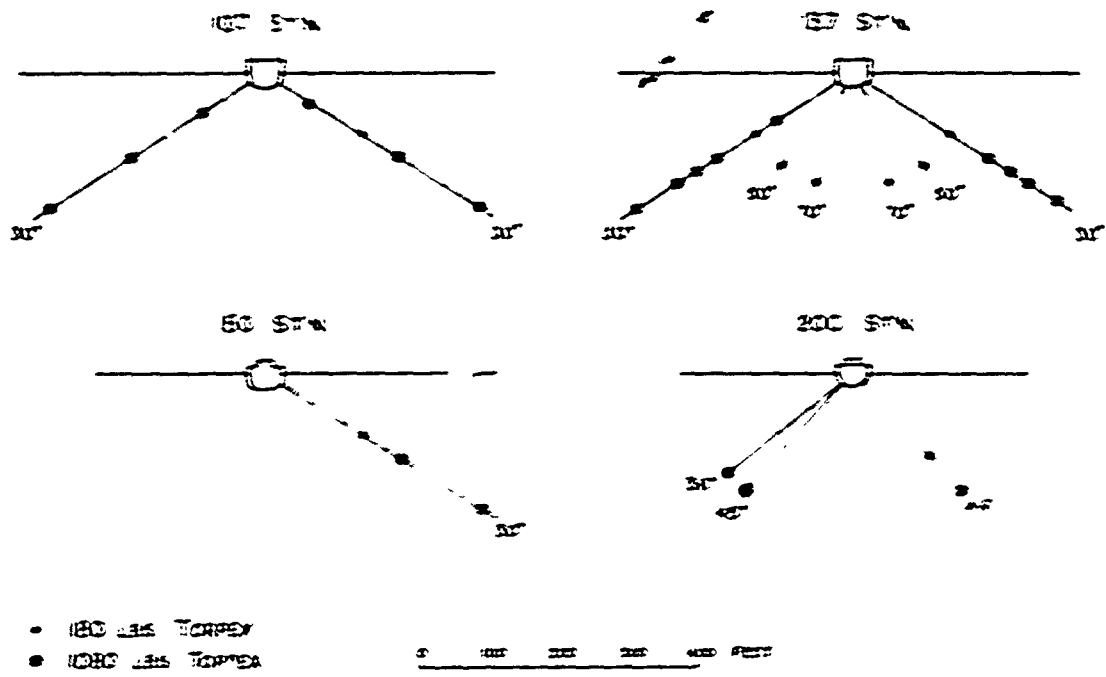


Fig. 28 HMS EBERARD. Charge Positions.

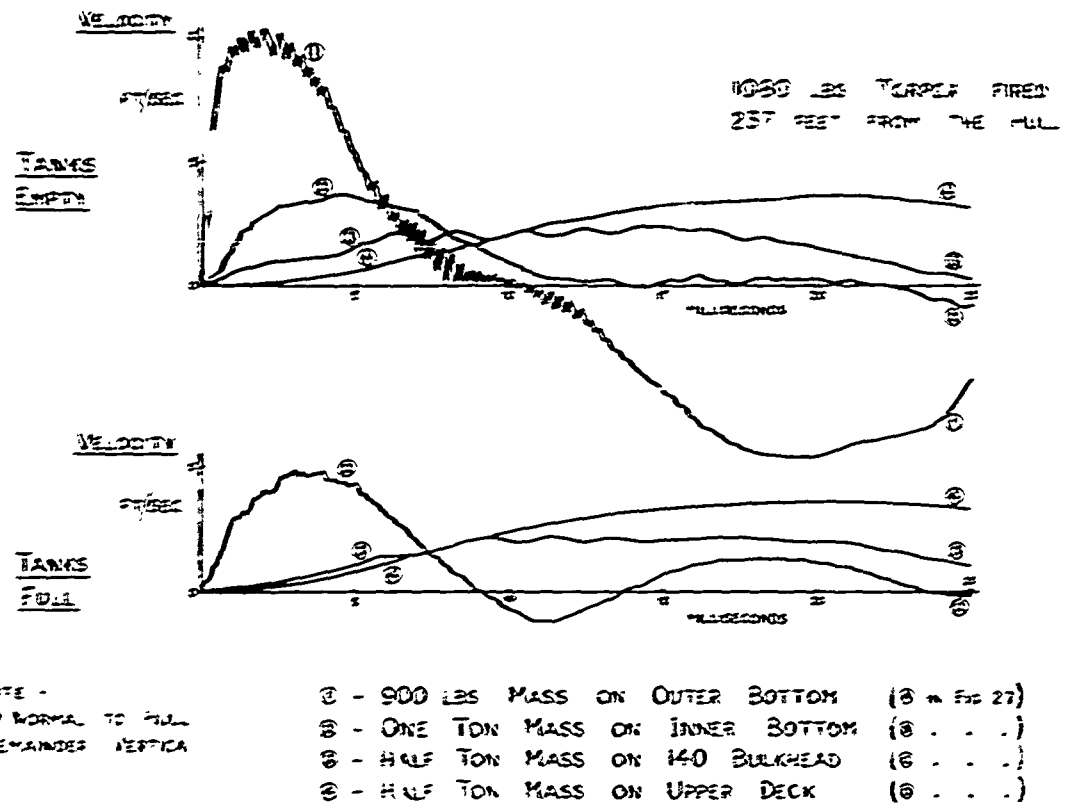


Fig. 29 HMS EBERARD. Velocity-Time Characteristics.

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ONE TON MASS ON JFC BULKHEAD 10 FEB 1941

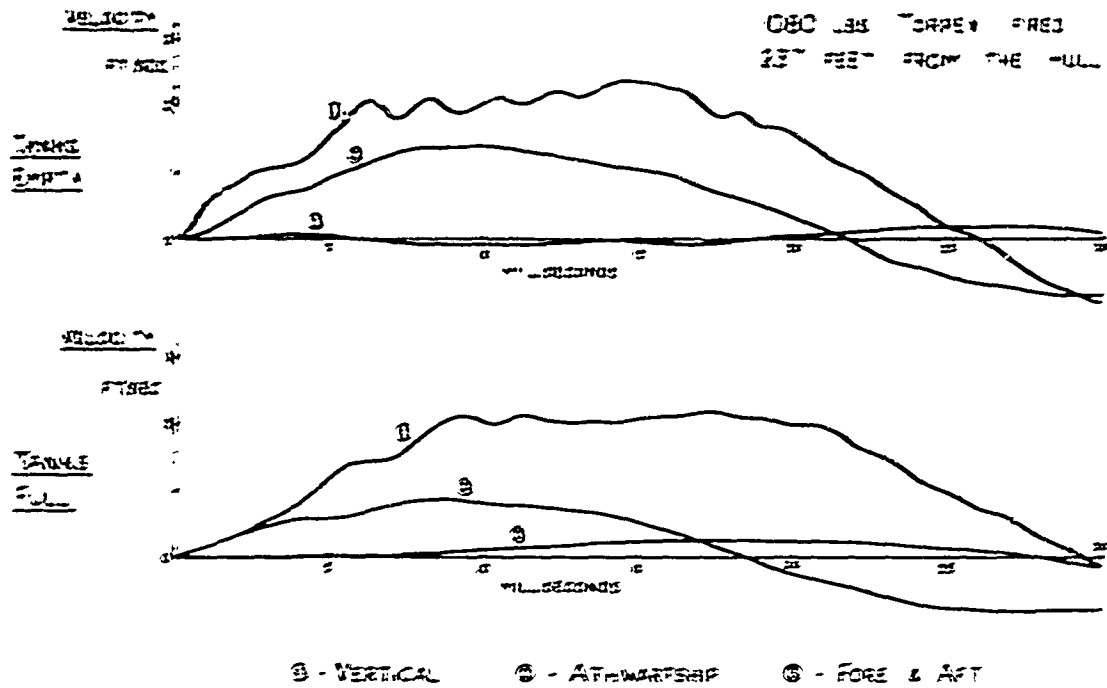


Fig. 30 HMS EMERALD. Velocity-Time Characteristics.

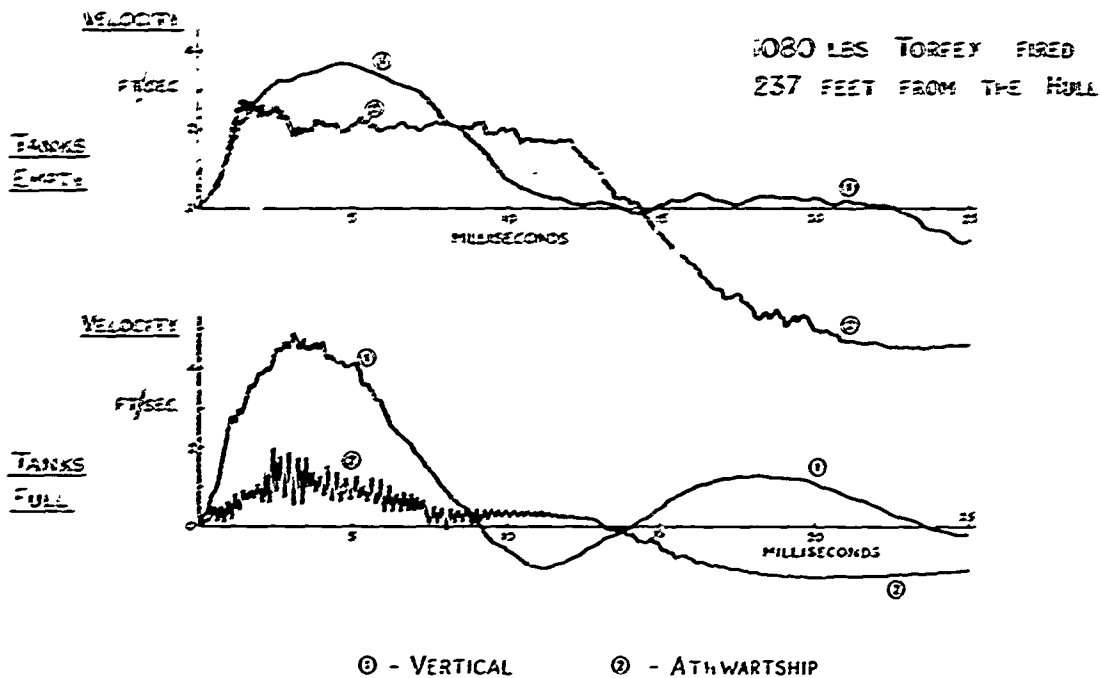


Fig. 31 HMS EMERALD. Velocity-Time Characteristics. 1-Ton Mass on Inner Bottom (B in Fig. 27).

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made, in conjunction with our knowledge of shock in different classes of ship, of the maximum severity of shock likely to be experienced in any position in each class of ship.

Design Figures for Shock

The simplest method to determine whether any mechanisms or, indeed, any item of naval equipment will withstand the shock characteristics and maximum severity of shock in ships caused by noncontact underwater explosions would be to secure it to a shock testing machine which produces similar shock characteristics and severities to those observed in ships. Such a machine would do the complicated shock mathematics and answer whether the item is good or bad from a shock viewpoint.

Obscure failures of mechanisms on shock machines can be examined in slow motion using high speed cine cameras, and remedies can often be indicated more rapidly by this means than by mathematical endeavour.

The characteristics of the ideal shock machine should be capable of alternation as regards frequency of oscillation, but this would result in a complicated machine; and it is felt that, provided the shock machine characteristics include the broad frequency bands observed in ships, the results will not be misleading except when testing items on flexible mountings.

The British policy is to design mechanisms like switch and control gear to withstand the shock tests when rigidly attached to the target plate of the shock machine and then to install the gear on flexible mountings in ships giving an added factor of safety.

The broad frequency bands for shock testing machines should include one band between 40 - 100 cps and one between 2 - 5 cps (the latter being associated with displacements exceeding 3 inches to simulate whipping movements).

TABLE III
H.M.S. EMERALD

ITEM	MAXIMUM VELOCITY FT/SEC			MAXIMUM ACCELERATION g			MAXIMUM DECELERATION g	1ST PEAK DISPLACEMENT INS
	VERTICAL	ATHWARTSHIP	FORE & AFT	VERTICAL	ATHWARTSHIP	FORE & AFT	VERTICAL	VERTICAL
900 LBS MASS ON OUTER BOTTOM (TANKS EMPTY)	30	-	-	1400	-	-	200	1.9
ONE TON MASS ON INNER BOTTOM (TANKS FULL)	20	13	-	400	100	-	75	1.8
ONE TON MASS ON INNER BOTTOM (TANKS EMPTY)	9	9	-	160	150	-	-	1.5
ONE TON MASS ON LOWER DECK	8	-	-	80	-	-	45	1.5
MASSES ON ATHWARTSHIP BULKHEADS	6	3	3	60	25	18	20	1.0

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It is our aim to produce a shock testing machine capable of shock testing machinery weighing up to 15 tons. The design of the machine has not been completed, but, briefly, it will consist of a catapult accelerator which strikes a 10-ton mass which, in turn, accelerates the target plate by means of hydraulic buffers. The target plate will be decelerated by means of hydraulic rams with adjustable parts attached to a 30-ton mass, so that the desired characteristics of shock may be obtained.

For machinery items, it has been the British practice to design auxiliary machinery, which in service is rigidly secured to the ships structure, so that the stresses in the machine do not exceed 16 tons psi for a load equivalent to 120 the weight of the machine vertically upward, 60 the weight of the machine vertically downward, and 60 the weight of the machine athwartship, applied at the supports of the machine; and the securing bolts are designed to have a stress of 25 tons psi under forces caused by a deceleration of 60 g

Machines so designed withstood accelerations of 220 g associated with a maximum velocity of 22 fps without mechanical failure or any measurable permanent distortion.

Whether this result was caused entirely by the obliging nature of mild steel increasing its yield point (due to the load being rapidly applied and only maintained for a short interval of time), or whether our method of assessing the mean accelerations gives unduly high figures, or whether the result was a combination of

both, cannot be positively asserted; but it would appear that machines manufactured of mild steel, D. W. steel, or cast steel and designed to withstand static forces of 120 g upwards 60 g downwards, and 60 g athwartship (applied at the supports of the machine) will withstand shock forces at the rates of loading and duration experienced in ships of almost double these figures.

It would appear from our trials that machinery when rigidly mounted in ships may experience shock forces in the vertical plane as listed in Table IV;

MAIN MACHINERY	vel. (fps)	acc. (g)
H. P. Turbines	8 - 10	100 - 120
L. P. Turbines	6 - 8	50 - 60
Boilers (measured at top of feet)	4 - 5	40
SUBMARINE MAIN ENGINES	12 - 14	100

AUXILIARY MACHINERY

(See also the supplementary Tables under "Comments").

Neither the deceleration nor the horizontal athwartship forces, in general, exceed one-half of the maximum values quoted above.

In order that the weight of machinery items may be kept within reasonable limits, it is felt that items of auxiliary machinery should be mounted on flexible mountings capable of reducing the shock accelerations to a figure not exceeding 120 g and that the auxiliary machinery should be designed as at present to withstand this magnitude of force, applied statically, without damage or distortion.

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TABLE IV
MAXIMUM VERTICAL SHOCK CHARACTERISTICS FOR MACHINERY

MAIN MACHINERY

H.P. TURBINES

VELOCITY
8 - 10 FT/SEC.

ACCELERATION
100 - 120 g

L.P. TURBINES

6 - 8 FT/SEC

50 - 60 g

BOILERS (AT TOP OF FEET)

4 - 5 FT/SEC

40 g

SUBMARINE MAIN ENGINES

12 - 14 FT/SEC.

100 g

AUXILIARY MACHINERY

POSITION	ITEM	CRUISERS		DESTROYERS		SUBMARINES	
		VELOCITY FT/SEC.	ACCELERATION g	VELOCITY FT/SEC.	ACCELERATION g	VELOCITY FT/SEC.	ACCELERATION g
ON THE SHIP'S BOTTOM	HEAVY MACHINERY 3 - 10 TONS	12 - 15	120 - 180	-	-	12 - 14	100
	MACHINERY ITEMS 1½ - 3 TONS	17	250	15	180 - 220	-	-
	MACHINERY ITEMS ¾ - 1½ TONS	20	400	16 - 20	150 - 250	20	250
ON THE UPPER DECK	MACHINERY ITEMS ¾ - 1½ TONS	8	80	7 - 16	45	-	-

ATHWARTSHIP VALUES RARELY EXCEED ONE HALF THOSE GIVEN ABOVE

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DISCUSSION

J. T. MULLER, BTL: In Figure 8 you show a negative velocity. How does that happen?

J. R. SHAW, R.N.S.S.: Figure 8 is a record of the motion of the deck. The deck receives its motion from the bulkheads which support it. It is conceivable that at times you will get a slightly downward movement (due to the supporting bulkheads being a bit out of phase) before the deck starts to move up.

I. VIGNESS, NRL: I would like to make one comment on the same subject. Mr. Muller knows the 4A plate on the lightweight shock machine. It is merely a flat plate supported by channels on two edges. We can have those two edges start moving forward with a certain velocity as the plate receives the shock excitation. When the two edges first move forward, the center of the 4A plate may move backward. This backward motion is easily observed in the acceleration records and is also noticeable if accurate displacement measurements are made. This backward motion can be explained by consideration of the rigidity of the plate to bending, in addition to the usual considerations of mass and tensile properties. This result can most easily be illustrated by the behavior of a bar when its center is quickly displaced a given distance perpendicular to its length.

Figure 32 illustrates the difference in response of a string (which will support no bending moment) and a bar when their centers are quickly displaced a given small distance perpendicular to their lengths.

For the string, the displacement kink moves at a uniform speed along its length, in manner illustrated by parts "b" and "c" of Figure 32. A location on the string partakes only of a single quick displacement as the kink moves by. However, when the center of a bar is quickly displaced, the shape of the bar at some first instant of time is shown in "e" of Figure 32. The ends of the bar are still in their original positions. The parts of the bar below the line connecting the ends have moved backward. Generally, the shorter the wavelength, the faster will be the propagation along the length of the bar, and thus the shape of the disturbance will continually change. A particle located at some position on the bar will first experience a vibratory motion about its original position. This vibratory motion will begin at very high frequency and very low displacement amplitude, and the frequency will become less and the amplitude greater as the waves pass down the bar. The bar will not vibrate about a new position until the point of inflection closest to its center has passed by. For simplicity, transients involved in stopping the bar have been neglected.

J.P. WALSH, NRL: In the CAMERON report you got shock characteristics up to a value of 0.2 and then guessed that in the plastic range of the hull the characteristic curve would have a slope of about one-half the slope in the elastic range and go out to a shock factor of 0.6. Has this been verified in later work, and are these values which you have shown maximum values up to the point of uncontrollable flooding?

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J. E. SHAW: First of all, you want to know, "Have we confirmed that the slope is about one-half when approaching the plastic range?" I don't think we have enough evidence to say so. Some of the results indicate that while the velocity may be about one-half, the acceleration against shock factor can be almost horizontal. We can get only about two shots per ship in the plastic range. That makes it difficult to get sufficient data to make sure of our ground. We are not certain that it is half the slope. The velocity looks like half the slope, but we are not sure that it is half the slope for acceleration as well.

In answer to the second part of your question, the maximum values that we have given are for some of the items which were actually measured, but others were extrapolated. For the extrapolation, we have taken half the slope of the curve in the elastic range. We may be a bit too high or too low.

J. P. WALSH: Up to what shock factor was this extrapolation made in order to get these maximum values?

J. E. SHAW: Up to the shock factor that we had on each ship. For instance for the submarine and for JOB 9 it was about 0.86. For the EMERALD it was around 0.8.

J. P. WALSH: There are the values at which you would expect uncontrollable flooding?

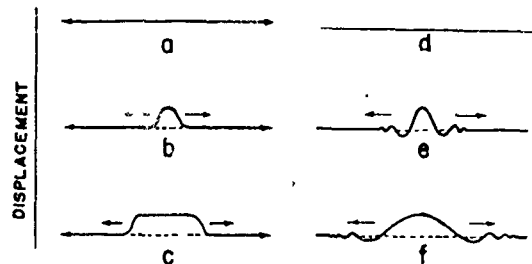


Fig. 32 Response of S ring and Bar to Quick Displacement.

J. E. SHAW: Yes.

J. P. WALSH: In the CAMERON report predictions were made and correlation was found for maximum velocity in terms of stiffness of plating, framing, etc. On the EMERALD, a double-bottom ship, were you able to confirm that?

J. E. SHAW: We have not done anything on that yet. Actually, on the EMERALD we have two problems.* With the space between the inner and outer bottoms full of water, anything on the inner behaves very similarly to the bottom of a single-hull ship. When the space between the inner and outer bottoms is empty, you get a cross between something on the deck and something on the bottom of a single-hull ship. We haven't the analysis finished yet. We are still only a very small team. This is being done, but it is not completed.

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CONTRASTING LAND VEHICLE PROCEDURES

By

*C. D. Montgomery,
Aberdeen Proving Ground*

The difference between a target ship trial and a land vehicle test makes a comparison difficult. My particular field involves land transportation, but the closest approach to this type of testing made by the Aberdeen Proving Ground on land vehicles was the qualitative tests performed on various wheeled and tracklaying combat vehicles to determine the most mine-resistant armor plate for various vehicle designs. The qualitative nature of this testing does not permit direct comparison with the test work described in the preceding papers; however, the description of another shock test on a light tank may be of interest.

Early experience in the war with the Medium Tank M3, having a riveted hull, gave the Armored Force disagreeable experience with a difficulty called secondary projectiles or missiles. The armor on this particular tank and others consisted of riveted structures which, when shocked, would cause the interior portion of many rivets to ricochet inside the tank. Riveted tank hulls were immediately replaced by welded hulls; however, then stowage brackets and various other types of mounting equipment which were originally attached to the armored plate became secondary projectiles. In addition to secondary missiles, electrical firing

circuits would open when impacted and instruments would be damaged. Possibly there were many other cases of combat vehicle component failures due to projectile impacts which were never thoroughly investigated.

The Ordnance Department was at this time in the process of launching a large manufacturing program for production of a Light Tank M5A1 which was a welded hull, and every effort was made to prevent secondary projectiles.

In the fall of 1942 it was decided to obtain test data on the impact shock phenomena and to supply design information for tank stowage mounts. The test objective was to establish a means of shock testing by firing at the tank with 37 millimeter and 75 millimeter proof projectiles. A proof projectile is a crudely made round simulating the mass of the more expensive armor-piercing rounds.

The 75 millimeter proof projectiles subjected the tank to an impact which was different from the type of shock caused by a hole-punching, 37 millimeter, armor-piercing round; however, the impact of the larger proof projectile might simulate the forces caused by an HE air burst or a mine blast.

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The Ordnance Department at Aberdeen Proving Ground had no experience with the shock effect of projectiles on tank armor except in a qualitative way, and, therefore, called upon Westinghouse, General Electric, and MIT to assist in this program. It was decided to measure accelerations, strains, and absolute displacements. The instrumentations to accomplish this were:

- (1) Piezoelectric type accelerometers with low pass filters where needed.
- (2) Time displacement records with a solenoid type of travel recorder.
- (3) High-speed motion pictures for absolute displacements.
- (4) Magnetic and resistance strain gages for the measurement of stress components.

Test procedure generally consisted of firing at representative areas of armored tank hull to simulate an anti-tank type of attack. The tank's armor varied from 1 1/8 to 1 1/2 inches in thickness.

Several reports were written covering the data of this test; in general, the results were grouped according to the location of the shocks as related to the impact area of the projectile. This is a convenient grouping, for the magnitude of the accelerations logically grouped themselves according to the following areas:

- a. Immediately behind the projectile impact,
- b. In the immediate structure,
- c. Remote from the impact area, or
- d. Isolated from the impact area by joints or resilient material.

It should be noted that the magnitude alone of the accelerations does not give an indication of the damaging forces; also, the phase relationships of the component structures tested probably cause a variation in test results.

The immediate vicinity of the projectile impact is considered within 12 inches of the

point of impact. Thus, the greatest acceleration measured was from approximately 8000 to 10,000 times the acceleration of gravity and in some instances as high as 9000 cycles per second. Crystal piezo accelerometers broke in this area, and it is possible that higher accelerations were present, if they could have been recorded. The impacting energies of the 37 and 75 millimeter proof projectiles used at the test velocities caused similar accelerations of the armor for both types of projectiles. There was an indication that the harder, armor-piercing type of projectile caused greater shock to the armor than the softer proof projectiles.

The absolute displacement of the turret when impacted was found to vary from 1/2 inch to 1 inch. Absolute displacements of the hull were approximately from 1/4 inch to 1/2 inch.

Much of this displacement may be accounted for by the roll of the vehicle's springing when impacted. Similar phenomena occur when a tank gun is fired.

When the impact shock was transmitted through the tank turret plate to the opposite side of the turret, it diminished to approximately 60 percent (that is, from 8500 g to 5200 g) and had about the same frequency. When the shock had traveled from the turret across a bearing joint to the tank hull, the shock value dropped to 40 percent of its original value.

Time in the order of a millisecond was required for the shock to be transmitted to those regions remote from the point of impact. As mentioned before, any discontinuity in the path caused the shock to be decreased; for example, the failure of the armor weld caused the shock to be reduced to 10 percent of its original value.

For vehicle components isolated by resilient mounts, the shock would decrease to approximately 1 percent of the original value. The tank engines were found to be nicely isolated by their normal rubber vi-

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bration mounts. Frequencies of the impact transmitted to the engine were reduced to approximately 10 percent of the original value for resiliently mounted items.

The rubber mounts attenuated the shock except in some cases where no snubbing or restrictions were provided to limit the absolute displacement. An example of this was the rubber mounts used on the tank instrument panel. The panel was thrown from its rubber mounts. As the test progressed, spring steel shock mounts were developed. In some instances these greatly reduced the shock to the order of 20 percent of the original impact value; however, sufficient room had to be left between the shock mount bracket and the instrument to prevent damage by the absolute displacement.

Strain gages used were mounted on various components in the vehicle. Strain and frequencies of the strain were measured on the object. In many cases, however, the material yielded and strain was only an

estimated value. Strain gages were particularly useful devices when a bending moment imposed on the component would indicate the relative severity of the force imposed on the structure of the component.

The greater use of shock mounts was probably the principal result of this test. However, there were other design changes which were of equal usefulness. Additional testing is needed in this field, and it is hoped that funds will be available for further investigation of tank shock effects, especially of mine-blast shocks.

REFERENCES:

1. G. E. Report No. 72346,
Shock Tests on Light Tank M5,
Oct. 21, 1942
2. W. E. Co. Res. Report SR-148,
Sept. 21 - 27, 1942

COMMENTS

The following tables were presented informally by Mr. Shaw at a Bureau of Ships conference. They contain design information by which the required strengths of machinery supports and major machinery parts can be determined. The design accelerations given are the result of velocity meter measurements taken during the British underwater, noncontact explosion field trials. The values given are about one-half the experimentally determined values. This factor of one-half was arrived at on the basis of damage observation of installed equipment and is accounted for by the increased yield

value of material under shock conditions and by other unexplained phenomena. Equipment designed to these values should withstand shock intensities that would cause uncontrollable flooding of the ship in the vicinity of the equipment. The items in Tables 1, 2, and 3 are for essential ship equipment. For less important items, where more breakage can be tolerated, Table 4 is included. It is to be noted that the values given may not be included in their final design specifications but are, at present, recommended values. The design values are applied as static values.

TABLE 1

MAIN MACHINERY		VERTICAL ACCELERATIONS							
	Position	Cruisers and Above		Destroyers		Submarines		Merchant Ships	
		Acc.	Dec.	Acc.	Dec.	Acc.	Dec.	Acc.	Dec.
		g	g	g	g	g	g	g	g
H. P. Turbines	On seating attached to inner bottom	50*	50*	50*	50*	--	--	20	15
	or outer bottom							to 40	to 25
L. P. Turbines	"	25*	25*	25*	25*	--	--	--	--
Gearing	"	50	30	50	30	--	--	--	--
Reciprocating Engines	"	50	30	50	30	50	30	--	--
Boilers	"	25	15	25	15	--	--	--	--
Main Motors	"	--	--	--	--	50	30	--	--

*On rigid resilient mounting. This mounting consists of a corrugated piece of material which acts as a rigid body until the forces reach certain definite values, after which the corrugated material crushes considerably for only a small increase in force.

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TABLE 2

AUXILIARY RECEIVERS AND ELECTRIC MOTORS		VESSEL'S ACCOMMODATIONS							
	Position	Cousins and Sister		Daughters		Siblings		Wardens	
		Acc.	Dec.	Acc.	Dec.	Acc.	Dec.	Acc.	Dec.
		1	1	1	1	1	1	1	1
Heavy Items, 3 to 10 tons	On inner bottom	51	51	1	1	1	1	1	1
	or outer bottom	91							
Medium Items, 11 to 3 tons	"	121	91	91	91	1	1	1	1
				121				1	1
Light Items, 2 to 11 tons	"	151	91	121	91	121	91	1	1
		1				1	1		
Light Items, 2 to 11 tons	Under exposed decks	121	91	91	91	1	1	1	1
		1							
Light Items, 2 to 11 tons	On bulkheads	91	91	91	91	1	1	1	1
Light Items, 2 to 11 tons	On inter- mediate decks	91	91	91	91	1	1	1	1

*Seem high. Tentative, based on single experiment.

TABLE 3

MINELAYS MACHINERY AND SUPPORT VEHICLES		ACCELERATION							
	Position	Cruisers and Albatross		Destroyers		Submarines		Merchant Ships	
		Acc.	Dec.	Acc.	Dec.	Acc.	Dec.	Acc.	Dec.
		1	2	1	2	1	2	1	2
Heavy Bomb. 3 to 10 times		20	20	--	--	--	--	--	--
Light Bomb. up to 3 times		40	40	--	--	--	--	--	--

Figures are given approximately
to ship rate

TABLE 4

LESS DEEPENING MINE		ACCELERATION							
	Position	Cruisers and Albatross		Destroyers		Submarines		Merchant Ships	
		Acc.	Dec.	Acc.	Dec.	Acc.	Dec.	Acc.	Dec.
		1	2	1	2	1	2	1	2
Workshop. Lam- ary. etc.	On inner bottom or outer bottom	40	25	40	25	--	--	--	--
Workshop. Lam- ary. etc.	On intermediate deck	30	15	25	15	--	--	--	--

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S A V I B U L L

A report of general interest to the members of the Shock and Vibration Symposium, entitled "Instruments for Measuring Vibration and Shock on Ship Structures and Machinery," TMB Report 563, will be available 15 August 1948. Characteristics of the various instruments discussed in this report are tabulated in Shock and Vibration Bulletin No. 3, May 1947. Copies of the completed report may be obtained by request from the David Taylor Model Basin, Technical Information Section, Washington, D. C.

Copies of the "Interim Definitions and Standards for Shock and Vibration" have been published and distributed. Written comments are invited, and discussion concerning these Definitions and Standards will take place at the next Symposium.

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